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Economic Geology

and the

Bulletin of the Society of Economic Geologists

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MOLYBDENITE DEPOSITS AND PEGMATITES IN THE PREISSAC–LA CORNE AREA, ABITIBI COUNTY, QUEBEC.*

G. W. H. NORMAN.

ABSTRACT.

An insight into the relationship between the molybdenite deposits, pegmatite and granite in this Quebec area is provided by a comparison of two granite masses and their associated deposits. The more deeply eroded granite mass is 13 miles long by 6 miles wide and has a marginal aureole ½ mile wide containing 50 per cent pegmatite. Banded pegmatite dikes with tantalite, beryl, and a few with a high per cent of quartz, and molybdenite, occur as the latest phase in the marginal aureole. The smaller granite mass is 3½ miles long and 1¾ miles wide. This mass has a border zone 10 to 50 feet wide high in pegmatite and is traversed throughout by quartz veins grading in places into feldspathic quartz veins that are indistinguishable from pegmatite. Molybdenite occurs in very small amounts in these quartz and feldspathic quartz veins throughout the granite and in conspicuous amounts in veins close to, or along the margin of this granite mass. The great similarity in the occurrence of tantalite, beryl and molybdenite in pegmatite in the marginal zone of the largest granite mass and of molybdenite in feldspathic quartz veins in the smaller mass suggests that their origin may be ascribed to very similar processes operating under slightly different physical conditions.

INTRODUCTION.

EXAMINATION of Canada's molybdenite resources has been greatly stimulated, by war needs, during the past few years. One of the most promising of the areas examined is the Preissac-La Corne area in Abitibi County, Quebec. This area lies about 400 miles northwest of Montreal and about 60 miles east of the Quebec-Ontario provincial boundary.

Molybdenite was first reported in this district, at Indian Peninsula on Kewagama Lake in 1901.[1] In the period between 1901 and the present war prospecting had disclosed molybdenite-bearing veins along a granitic belt

* Presented before the Society of Economic Geologists, New York meeting, Feb. 21–24, 1944.

[1] Eardley-Wilmot, V. L.: Molybdenum. Canada Dept. of Mines, Mines Branch, No. 592, p. 127, 1925.

about 30 miles long extending south of east from Indian Peninsula in Preissac township across La Motte and La Corne and into Fiedmont township. Work to date has centered chiefly on those at Indian Peninsula, and on others at the southwest corner of La Corne township. The Indian Peninsula deposits were extensively tested at the surface during the last war, and in 1919 a 100-ton mill, since burnt, was completed, but operated only a few days. In 1942 Dome Exploration (Quebec) Ltd. outlined an orebody by drilling near the old surface workings at the peninsula. Indian Molybdenum Ltd., the company organized to carry on the operations, has sunk an inclined shaft to intersect the orebody and feed a 500-ton mill completed in September 1943. The La Corne deposit, which consists of a series of quartz veins, was explored on two levels from an inclined shaft between 1927 and 1930. This deposit was reopened in 1942 by Wartime Metals Corporation Ltd., and the mill was improved and enlarged to handle 200 tons daily.

Besides Molybdenite, the Preissac-La Corne area contains spodumene, tantalite, and beryl-bearing pegmatites. The occurrence of these minerals has attracted attention and many showings of these minerals have recently been staked. The distribution of the molybdenite and pegmatite deposits illustrates certain aspects of the zonal theory of ore deposition. This paper, therefore, presents an outline of the mode of occurrence and relationships of the molybdenite and pegmatite deposits as it is felt that greater clarity regarding their origin is thereby obtained.

GEOLOGY OF THE DISTRICT.

General Features. The Preissac-La Corne area lies in one of the major gold-producing regions of the Canadian Shield. The oldest rocks of this district are Archæan lavas, pyroclastics, greywacke and conglomerate. These surficial rocks are intensely folded, faulted, and distorted and are intruded by dikes and sills of basic to ultrabasic igneous rocks. The volcanic, sedimentary, and basic to ultrabasic rocks are intruded by dikes, plugs, stocks, and batholithic masses of syenitic to granitic rocks. In gold-producing localities the syenitic to granitic rocks are generally high in soda and contain albite or oligoclase as the sole or predominant feldspar. In the Preissac-La Corne area and other localities these younger intrusives contain more potash than soda, shown by their high microcline content. Late Precambrian diabase dikes are the youngest intrusive rocks in the district and are remarkable for their persistency and prevailing northeast trend.

In this area, unlike gold-producing sections of the region, intrusive rocks have displaced or metamorphosed the Archæan volcanic and sedimentary rocks to such an extent that evidence of their original structure, believed to be anticlinal, is almost completely obliterated. On either side of the area of metamorphic and intrusive rocks, belts of highly faulted and folded Archæan rocks occur and are intruded only by small or comparatively small bodies of granitic rocks. The belt south of the Preissac-La Corne area is part of the Kirkland Lake-Bourlamaque gold belt, and that to the north lies east along the strike from the Porcupine-Beattie belt.

Preissac-La Corne Area. The general distribution of rock types and a rough outline of the structure of the area is indicated in Figure 1. The most important features of the geology in relation to the molybdenite and pegmatite deposits are the granitic bodies. It is noteworthy, however, that about 50 per cent of the pre-granitic rocks that lie in the anticlinal area between the two belts of greywacke consist of layered peridotite masses, in places of great thickness. Outside the two sedimentary belts peridotite occurs only in the northern lava belt and there only as comparatively thin sills. This distribution shows that even prior to the intrusion of the granite the central part of the area was invaded by larger masses of intrusive rocks than adjoining parts. The general trend of the major structure of the area is indicated by the two belts of greywacke. The change in trend of these belts in the eastern part of the area is part of a major warp that extends as a cross structure northeastward across the district. This Z-shaped structure or drag suggests a relative movement on the north, eastward, and local structures including those which have exercised control on molybdenite deposition may perhaps have been influenced by this relative movement.

GRANITES OF THE PREISSAC-LA CORNE AREA.

The molybdenite and pegmatite deposits in Preissac, La Motte, and Figuery townships (Fig. 1) are associated with two large masses of garnet-

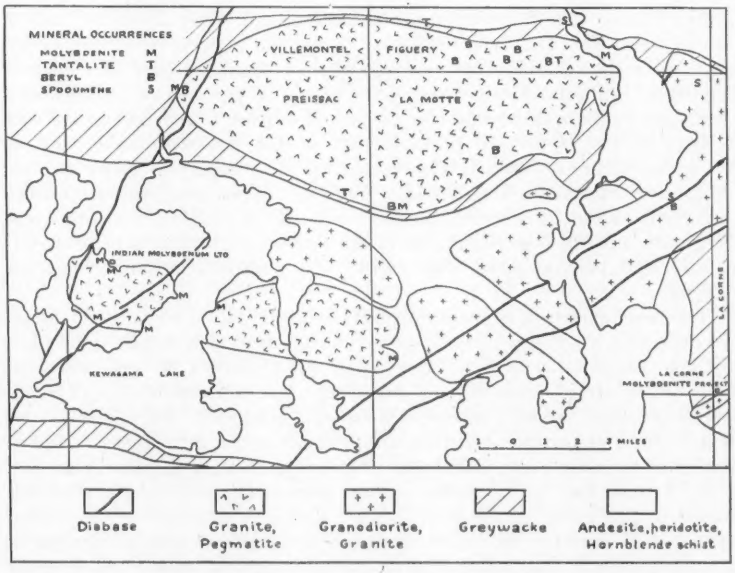

FIG. 1. Generalized geological map, Preissac and La Motte townships, Quebec.

iferous biotite and muscovite granite. These will be called the La Motte mass which lies to the north and the Preissac mass on the south. Besides these two large masses there are numerous smaller granitic bodies that range in composition from biotite-hornblende granodiorite to biotite granite. These rocks contain less microcline and a more calcic plagioclase than the garnet-iferous mica granites. They are cut in places by small red aplite dikes but pegmatite phases either as dikes or segregations are rare. Conclusive evidence that at least some and probably all of these smaller biotite granite bodies are older than the garnetiferous mica granite is shown by cross-cutting relationships at the Indian Peninsula molybdenite deposits. All these rocks are presumably variants from a common stem and are probably related genetically.

A comparison of the La Motte and Preissac granites illustrates different stages in differentiation reached in these two masses and the corresponding type of associated deposits. The composition of the typical granite of the La Motte and Preissac masses is very similar, but in other respects the two masses differ considerably. In both the biotite phase consists essentially of quartz, microcline, albite (An 6 to 10 per cent) and biotite with small amounts of wine colored garnet that are locally conspicuous. The muscovite phases have a similar composition with muscovite in place of biotite. The boundary of the La Motte mass cannot be precisely defined because of numerous narrow bands of biotite schist alternating with granite about its margin. The boundary of the Preissac mass where exposed at a few places is sharp and distinct. The La Motte granite shows a marked foliation due to parallel arrangement of mica flakes. The Preissac granite is massive and rarely shows any indication of foliation. The most important distinction between the two masses, however, is the relative proportion and type of pegmatite that they contain. Pegmatite, in the La Motte mass, forms nearly 50 per cent of the rock in a zone ½ to 1 mile wide around the border and at least 10 per cent of the rock in the interior. Only the western part of the Preissac mass, west of Kewagama Lake, is sufficiently well exposed for comparison of the pegmatite content with the La Motte Mass. Pegmatite in this western part forms a border zone 25 to 50 feet wide on the north side of Indian Peninsula where the granite margin is exposed, but in the interior pegmatite is present only as rare and narrow dikes, and quartz and feldspathic quartz veins are abundant.

The development of pegmatite in the La Motte mass may be divided into two main stages. In the early stage the emplacement of pegmatite took place partly by segregation and probably partly by a process of replacement as these bodies are of irregular size and shape, are without clearly definable boundaries, and contain numerous inclusions of granite. Pegmatite of this stage consists of perthite, quartz, and muscovite and a little garnet. In the later stage pegmatite was introduced as irregular branching dikes a few feet to 25 or more feet wide. Some of these pegmatites, particularly near and parallel to the border of the granite, have a banded structure. The banded types contain quartz in the center, margined by muscovite zones, and these in turn pass abruptly into zones of graphically intergrown quartz and feldspar (albite and perthite) which form the main part of the dikes. Streaks of

small wine colored garnet occur in the quartz feldspar zones parallel to the walls of the dike and a little green chrome spinel is also present. The quartz centers form vein-like masses 1 to 2 feet wide or short discontinuous lenses. The muscovite zones are 6 inches or less wide and consist of crenulated mica flakes 1 to 3 inches in diameter with a little included garnet in places. Tantalite and beryl if present commonly occur along the outer edge of, and to a minor extent within, the muscovite zones. Molybdenite occurs in the quartz veins and lenses of some of the pegmatite dikes as large flakes and segregations an inch or more in diameter.

Pegmatites of the early stage, consisting of perthite, quartz and muscovite, as in the La Motte mass, occur as segregations and replacements in the narrow border zone of the Preissac mass and as narrow dikes with minor aplite in its interior part. The complex and banded pegmatites of the later stage in the La Motte mass are, however, lacking and their probable counterpart in the Preissac mass are abundant quartz and feldspathic quartz veins. The Indian Peninsula quartz veins strike for the most part east-southeast roughly parallel to the axis of the granite mass, and to a lesser extent southeast or more rarely nearly north. Veins in the northern part of the granite dip 60 to 70 degrees south on the average. On the south side they dip steeply north but north-dipping veins are not sufficiently numerous to clearly indicate a symmetrical fracture pattern about the axis of the granite.

Quartz veins are particularly numerous in the light colored, medium grained muscovite granite which underlies the western part of Indian Peninsula directly south of the Indian Molybdenum mine. The muscovite granite grades fairly abruptly though imperceptibly into a red biotite granite that underlies the eastern part of the peninsula, and contains a higher proportion of garnet than the biotite phase. Veins in the biotite granite are widely separated, are mostly 6 inches to 1 foot wide and only exceptionally reach widths of 5 to 10 feet. In the western muscovite granite section, particularly west and southwest of the mine (Fig. 2), the veins are closely spaced in swarms and range from 2 to 12 feet—and at one place 50 feet—wide; if concentrated at one place they would form a body of quartz of impressive size.

Quartz is the major, in many practically the sole, constituent of the veins. Many contain, besides quartz, microcline, muscovite and a little molybdenite. Other veins near the margin of the granite, near the mine, contain in addition to these minerals appreciable though very unevenly distributed amounts of molybdenite, with coarse cubic pyrite, and very small amounts of bismuthinite, fluorite, and more rarely tantalite-columbite. Beryl and tourmaline, also, are present in similar veins outside of the Preissac mass at the La Corne mine to the east. In the Preissac mass every gradation in composition occurs from veins in which the sole constituent is quartz to veins with a high proportion of microcline. Microcline, if present, occurs characteristically either as long crystals extending inward normally from the walls or as solid masses or border zones on either side of the quartz. Isolated squat shaped crystals of feldspar 1 foot in diameter occur in the interior of some veins and others have 1 to 2 inch wide selvages of coarse mica along their walls like those which margin the quartz in the central part of some La Motte peg-

matites. The feldspathic quartz veins have the appearance of extremely siliceous pegmatite dikes. As there are examples of every gradation from those with a high feldspar content to those consisting of nearly pure quartz they probably form a closely related group, though perhaps introduced in successive stages with corresponding changes in composition. These veins would seem to represent a stage in differentiation corresponding to the quartz

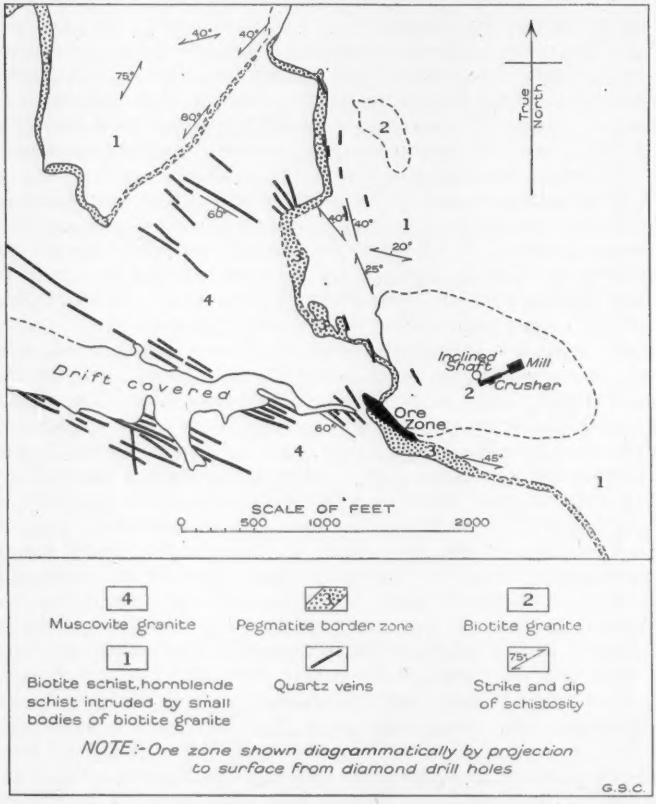

FIG. 2. Vicinity of Indian molybdenum mine, Preissac township, Quebec.

zones in the centers of the banded pegmatite dikes of the La Motte mass. The occurrence of small amounts of molybdenite with the quartz zones and quartz-rich parts of the banded pegmatites in the La Motte mass, and the more widespread concentrations of molybdenite in the quartz veins near the margin of the Preissac mass, suggest a similar mode of origin and support the theory

that the quartz veins at Indian Peninsula are closely allied to pegmatites as suggested by others.[2]

It may be argued that the occurrence of abundant garnet in the pegmatite dikes of the district, its presence in conspicuous amounts in the muscovite granite of Indian Peninsula and its more rare occurrence in the biotite granite indicate successive stages in differentiation. It is possible, therefore, that the muscovite granite though gradational into biotite granite at Indian Peninsula may represent a slightly younger phase, perhaps filling a conduit up which granite magma ascended to form the Preissac mass. This possible relationship of the two granites would help to explain the prevalence of quartz veins in the muscovite granite, the concentration of molybdenite on its north side at the mine, and the local occurrence of molybdenite disseminated here and there in the muscovite granite at a distance from any vein quartz. The presence of garnetiferous muscovite granite dikes cutting older rocks, including biotite granite, near the mine rules out the possibility that the muscovite was formed by alteration induced by the solutions forming the quartz veins.

The contrasting features of the La Motte and Preissac masses may be due to differences in original composition or to greater depth of erosion of the La Motte mass, or to a combination of these conditions. The probable explanation of the lack of sharp contact, and distinct foliation of the La Motte mass and the sharp contact, lack of distinct foliation and the fracture patterns brought out by the quartz veins in the Preissac mass; is that the former mass was either more fluid during intrusion, or is more deeply eroded. The quartz veins in the Preissac mass have an en echelon arrangement in places (Fig. 2) that indicate rupture of a solid mass. As the mineralogical evidence strongly favors a close relationship between the quartz veins and pegmatite, their presence in a definite pattern within the Preissac mass can only be explained by assuming that the upper solid crust of this mass was deformed and ruptured during a late stage in its emplacement thus providing suitable channelways for deeper seated solutions concentrated in the crystallizing magma beneath to ascend and fill.

TANTALITE, BERYL, AND SPODUMENE-BEARING PEGMATITES.

Although a structural control, except in its broadest sense, is lacking, there is a very definite grouping of tantalite, beryl and spodumene-bearing pegmatites in relation to the La Motte granite in Preissac, La Motte and Figuery townships (Fig. 1). Tantalite and beryl though nowhere present in large amounts occur more commonly in pegmatites near the border of this granite mass than elsewhere. Indeed most of the occurrences of these two minerals are within or close to the border zone of this granite and their presence at any distance from this granite is rare. Molybdenite, also, is present in small amounts in the border zone of this granite, particularly at

[2] Bancroft, J. A.: Report on the geology and mineral resources of Keekeek and Kewagama Lakes region. Mines Branch, Dept. of Col. Mines and Fisheries, Ann. Rept.: 175–176, 1911. Gerrie, William: Molybdenite in La Corne and Malartic Townships. Univ. of Toronto, Studies, Geol. Series No. 24: 39, 1927. Hawley, J. E.: Molybdenite deposits of La Corne Township, Abitibi County. Quebec Bur. of Mines, Ann. Rept., pt. C.:119, 1930.

its western end. Silicious pegmatites, there, contain crystals and bunches of molybdenite 1 inch or more in diameter in places, and about 1,200 pounds of molybdenite is reported [3] to have been cobbed and shipped from one of these pegmatite dikes, at the Height of Land property, at the extreme west end of the granite. The spodumene-bearing pegmatites occur in greywacke, greenstone, and granite for several miles eastward from the Preissac granite. The original presence of spodumene in pegmatites within the Preissac granite is suggested by plume-like aggregates of fine musocite scales, 1 to 8 inches long. These aggregates have sharp boundaries and a shape and arrangement normal to the walls similar only to that of spodumene in pegmatites in the district. The grouping of tantalite and beryl-bearing pegmatites within or close to a granite mass and of spodumene without and at some distance from it compares closely with a similar grouping present north of Great Slave Lake in the Northwest Territories of Canada.[4]

Tantalite. The most important tantalite discovery in the area lies 3½ miles south and ½ mile west of the northeast corner of Preissac township. This occurrence forms part of a pegmatite dike cutting the La Motte granite about 1,000 feet north, and parallel to, its south border. The dike can be traced for about 500 feet eastward across a knob of granite and dips about 15 degrees north. At its eastern end it is about 20 feet wide, but its width is irregular due to its branching and braided structure. Tantalite occurs as isolated small crystals at points along the exposed length of the dike and is concentrated in a small shoot about 60 feet long and about 10 inches wide at its extreme eastern end. The eastern end of the dike has a banded structure consisting of a central series of quartz lenses margined by coarse muscovite which in turn pass abruptly into a coarse quartz-albite zone containing streaks of red garnet, minor beryl and green chrome spinel, and a few large masses of perthite. Tantalite occurs as individual crystals ranging in size from minute specks to others ¾ inch wide by 3 inches long, and as radiating crystal clusters, replacing albite and quartz directly beneath the lowest muscovite zone. A concentration test of a 70 pound shipment from this tantalite zone by the Ore Dressing and Metallurgical Laboratories, Bureau of Mines, Ottawa, showed a tantalite content of .65 per cent or 13 pounds to the ton. Analyses of the concentrates, whose specific gravity was 6.2, gave:

	Per Cent
Ta_2O_5	54.17
Cb_2O_5	26.37
Fe	6.73
Mn	5.10
TiO_2	.36

To test possible variations of the Ta_2O_5 content of tantalite from this zone specific gravity tests were made on ten very carefully prepared specimens by H. V. Ellsworth of the Mineralogical Division of the Geological Survey, Ottawa. These results gave a range from 6.25 to 6.64 but in the greater number of cases the specific gravity approached the mean average of 6.43.

[3] Eardley-Wilmot, V. L.: Molybdenum. Canada Dept. of Mines, Mines Branch, p. 129, 1925.

[4] Jolliffe, A. W.: Personal communication.

The only other tantalite occurrence in the district that has been trenched and opened up for examination is situated near the southwest corner of Figuery township. This occurrence is in a pegmatite dike 5 feet wide which extends vertically northwestward across a peridotite outcrop about 1,000 feet north of the La Motte granite. The main part of the dike consists of coarse albite with 30 per cent quartz, margined sharply on either side by fine grained aplite of the same composition containing streaks of red garnet. Along the center of the dike are discontinuous lenses of quartz 1 to 2 inches wide. Tantalite occurs as conspicuous crystals in places along the dike, but the majority of crystals are very small and the percentage of tantalite throughout is very low. Specific gravity tests on one large crystal gave an average of 6.26 which indicates about the same Ta_2O_5 content as in the Preissac occurrence.

A few small crystals of tentalite have a specific gravity of 7.175, the highest recorded from the district and indicating a Ta_2O_5 content of 65 to 70 per cent, were collected from a dike near the south border of the granite, 1½ miles east of the Preissac tantalite pegmatite.

Beryl. Many of the pegmatites in the border zone of the La Motte granite, particularly in its northeast part, contain small amounts of pale green cloudy beryl. Beryl also occurs as a minor constituent of the spodumene-bearing pegmatite east of the La Motte granite and in one of the easterly trending molybdenite-bearing quartz veins at the La Corne Molybdenite mine. The crystals in the La Motte granite pegmatites vary from ¼ to 1½ inches in diameter and from 1 to 4 inches in length. Like the tantalite they are particularly common in dikes containing central bands of quartz margined by muscovite and similarly are associated with or close to the muscovite bands. Dikes containing beryl range from a few inches to 20 feet or more wide, but the beryl crystals are widely separated, most commonly along definite bands, and the proportion of beryl in the numerous dikes inspected proved to be very low.

Spodumene. The area containing spodumene-bearing pegmatites extends eastward for at least 13 miles, and southeastward 10 miles from the east end of the La Motte granite (Fig. 1). In view of the wide distribution and relatively high concentration of spodumene in many of the dikes the reserves of spodumene in the district may prove to be large. The spodumene-bearing dikes, unlike those with tantalite and beryl in the La Motte mass, have sharp tabular, steeply dipping walls, and a fairly constant composition throughout, with rare instances of banding. They range from a few feet to 30 feet wide and can be traced for hundreds of feet. Albite, microcline, quartz and spodumene are the chief constituents of these dikes, accompanied by minor muscovite and in places by a little pale green to pale blue beryl and more rarely tantalite-columbite. The textural relations of the four chief constituents compare with those of a very coarse grained igneous rock, except in local segregations where the crystals are 1 foot or more in size. In the coarse segregations spodumene crystals may be 2 inches wide by 18 inches long and in one reported case 4 feet long. In some dikes feldspar, quartz and spodumene occur in very nearly equal proportions and a Rosiwal analysis on a

large specimen from one dike indicated about 20 per cent spodumene by volume equivalent to nearly 24 per cent by weight. The spodumene content of the dikes, however, though seemingly constant in any one dike, varies, and in some dikes spodumene is restricted to local concentrations. An analysis of spodumene from one dike gave:

SiO_2	63.72
Al_2O_3	26.24
Fe_2O_3	.90
FeO	trace
CaO	.22
MgO	.16
Li_2O	5.77
Na_2O	2.25
K_2O	.03
MnO	.06
TiO_2	.06
H_2O	.52
	99.93

Analyst R. J. C. Fabry, Section of Mineralogy, Geological Survey, Ottawa.

MOLYBDENITE DEPOSITS.

Local structural control, which is lacking in the pegmatite deposits of the district, plays an important role in molybdenite deposition at the Indian Molybdenite mine on the north side of the Preissac granite mass. The relationship between structure and molybdenite deposition there suggests that structure should be an important factor in other deposits in the Preissac-La Corne district. At the La Corne molybdenum mine, vein systems, with a definite structural pattern, occur at a granite-greywacke contact but lie mostly beneath a sand plain and the relationship of the deposit except to the structure in a very confined area is unknown. Molybdenite-bearing veins occur at several other localities in the Preissac-La Corne area. Those in the western part of the district in Preissac and La Motte townships lie near the border of the Preissac granite and their distribution is comparable to that of tantalite and beryl about the border of the La Motte granite. Data regarding the structure of these occurrences, the majority of which are too small to be of economic interest, are scanty due to scarcity of outcrops in their vicinity. In La Corne and Fiedmont townships in the eastern part of the district molybdenite-bearing veins occur in greenstone, biotite schist (altered greywacke), and granite. The structure in the vicinity of these veins is unknown, but unlike veins in the western part of the district they do not seem to be associated with any one granite mass.

Indian Molybdenum Deposit.[5] The Indian Molybdenum deposit lies near the center of the west half of Preissac township between two faults in muscovite granite at the north contact of the Preissac granite mass (Figs. 1 and 2). The marginal zone of the granite consists of muscovite granite, grading in places into biotie granite, with segregated masses or dikes of coarse quartz-

[5] Data, and geological maps by Dr. B. J. Keating, were very kindly placed at the writer's disposal by Mr. J. G. McCrea, General Manager of Indian Molybdenum Ltd. and greatly facilitated study of the deposit. The writer, however, accepts responsibility for any conclusions.

perthite muscovite pegmatite and is useful as a local horizon marker in indicating fault movements and gently plunging rolls of the granite contact. As its thickness appears to remain fairly constant, the width of the horizontal exposure of this zone roughly indicates the steepness of the dip of the contact. Near the mine where the dip is about 40 degrees northeast the zone is wide but in the large V-shaped indentation northwest of the mine (Fig. 2), the dip in places is steep or vertical and the zone is correspondingly narrow. Directly northeast of the deposit, white to pinkish muscovite granite is in contact with a small body of an older grey porphyritic biotite granite, and on either side of this body with biotite hornblende schist. The schist shows banding in places and contains zones with drawn out fragments, but is unlike the typical altered greywacke of the district and is probably an altered tuff. In places directly in contact with the granite the biotite content of the schist increases to nearly 100 per cent. Interlayered with the schist are a few irregular sill-like bodies of foliated diorite and on its western side in the V-shaped indentation northwest of the mine are peridotite and minor pillowed greenstone. The strike and dip of the schists conforms roughly with that of the granite contact. There is, however, an apparent repetition of schists and other rocks, including a layer with fragments and a zone with quartz and massive to disseminated pyrite that suggests duplication by faulting on either side of the narrow northeast extension of muscovite granite northwest of the mine.

The two faults that bound the orebody (Fig. 3) are about 40 feet apart. They dip 40 to 50 degrees northeast and strike southeast about parallel to the series of quartz veins in the granite to the west and at a slight angle to the general more northerly trend of the granite contact. The character of the faults is known only underground in the mine. The footwall fault there has a sharp slip surface with relatively massive rock on either side. The hanging wall fault is fairly sharp in places but in other places branches and consists of a zone of intensely crushed and altered granite several feet wide cut by molybdenite-stained gouge filled slips. A horizontal shift eastward along the northeast sides of the faults is indicated by the duplication of the pegmatite border zone. This zone occurs at the muscovite-biotite granite contact in the inclined adit (Fig. 3), and in the face of the adit, separated from the footwall fault by a few feet of biotite schist, which indicates that the footwall fault at this point is nearly along the granite-schist contact. The facture pattern between the faults suggests that they are of the reverse or thrust type.

Figure 3 illustrates the general structure of the orebody and the arrangement of the network of quartz veins that it contains. From the hanging wall fault southwestwards across the greater part of the orebody gently dipping quartz veins 6 inches to a foot wide occur at intervals in the granite and are connected by steeply dipping quartz stringers. The veins increase in number near the footwall fault along which they coalesce, to form a solid vein of quartz. This vein contains about 5 per cent red feldspar as scattered bunches of coarse crystals and is 12 feet wide in places. Granite directly above this wide vein for 10 feet or more occurs as isolated lenses and blocks surrounded by quartz. Deformation after the introduction of the quartz, produced small

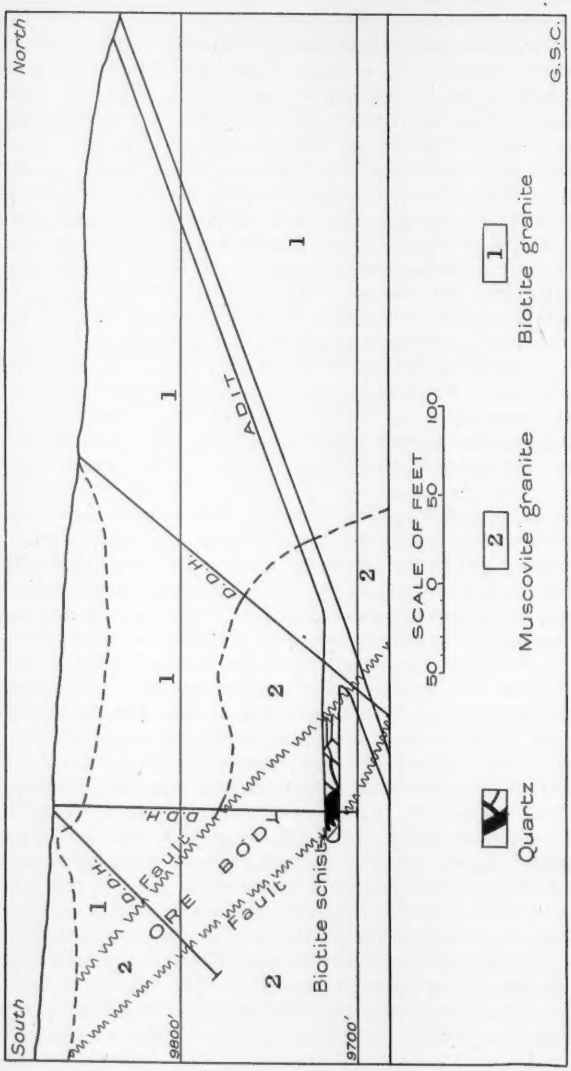

FIG. 3. Adit cross section, Indian molybdenum mine, Preissac township, Quebec.

slips in the quartz and intervening granite of the orebody roughly parallel to the footwall fault, along the sides of many of the veins, and about granite lenses surrounded by quartz. These surfaces are lined with muscovite and fine grained molybdenite which along some occurs in conspicuous amounts. Some veins show little indication of deformation, and these unlike the sheared veins contain in places white feldspar (microcline) and hexagonal plates of molybdenite. Molybdenite also occurs sparingly in places disseminated as small flakes in the granite distant from any veins.

The extension and character of the orebody on either side of the underground workings is known only in drilling. The drilling indicates that the orebody ends southeastward where the faults pass out of the granites into or along the sides of a wedge of schist which comes in between the older biotite granite to the northeast and the main muscovite granite to the south. Northwestward the orebody passes into relatively barren granite. Directly northwest and along the strike of the ore zone at the surface is a drift-filled depression 50 feet wide and 400 feet long. This depression probably marks the northwest extensions of the faults. The blocky fractured character of the granite at the northwest end of the depression suggests that the faults branch into a wide fracture zone in passing away from the contact into the granite.

In estimating the probable downward extension of the orebody, a choice between two alternative mechanisms of structural control has to be made, and in this connection attention is called to (1) the wedge-shaped mass of schist directly southeast of the orebody, (2) the en echelon series of quartz veins directly west of the orebody, and (3) the bend in the granite contact in its vicinity. The differences in physical character between the schist and granite would produce entirely unlike results during deformation. A wedge-shaped body of schist extending into the granite would not only offer ease of movement throughout along cleavage planes but also a zone of weakness along which movement would be concentrated. The localization of strain in the granite at the end of the wedge would produce a fracture zone and if sufficiently great a fault zone. If there were no other facts to be accounted for the localization of the orebody could be ascribed to the presence of the wedge-shaped mass of schist and the downward extension of the orebody would depend on the configuration of the schist wedge in the deeper parts of the mine.

The en echelon system of quartz veins indicates a zone of rupture in the granite extending for more than 2,000 feet west from the orebody. It is notable that the ore zone faults occur at the intersection of this zone and the granite contact at a point where the contact makes a sharp bend. The arrangement of veins in the en echelon zone seems to indicate a relative easterly movement on its north side, similar to that along the ore zone faults. The similarity of these relative movements and the location of the orebody at the intersection of the rupture zone and the granite contact suggests a common structural control for their development; and the similarity of the vein material in the orebody and in the en echelon veins points to their formation from a common source of mineralizing solutions even though temperature may have played an important role in concentrating the molybdenite in these

solutions near the granite contact. These relationships suggest that the donward extension of the orebody should lie along the rake of the intersection of the en echelon vein system and the granite contact. The bend in the contact may have been produced during the deformation that gave rise to the en echelon zone or may have controlled the location of this zone and perhaps has an important bearing on the dip of the en echelon zone and its continuity with depth. If the structural control of the orebody is the intersection of a rupture zone with the granite contact, that is of two more or less plane surfaces, greater depth than lateral extent would normally be expected. A test of the concentration of molybdenite deposition at the intersection of en echelon vein systems and the granite contact, as outlined above, could be made by drilling 1,300 feet northwest of the mine. The granite contact there, as at the mine, makes a sharp bend, and extending west from this bend is another series of en echelon molybdenite-bearing quartz veins.

The close connection between molybdenite deposition and structure shown by the structure of the orebody is also indicated by the greater concentration of molybdenite in deformed rather than in undeformed veins. Undeformed veins near the contact in the vicinity of the mine and even in the orebody itself contain microcline much in excess of muscovite and molybdenite, in part, as hexagonal crystals. In the deformed veins numerous slip surfaces occur lined with muscovite and molybdenite and only minor amounts of feldspar are present. The relationship between deformation and molybdenite deposition is very convincingly shown also in the mine where the general succession of events appears to have been:

(1) Faulting, and fracturing of granite between the two faults.

(2) Infiltration of quartz with minor microcline, molybdenite and pyrite along the footwall fault and progressively upwards along fractures from this fault.

(3) Deformation of the orebody producing slip surfaces accompanied by the development of muscovite and molybdenite along these surfaces, and alteration of much of the original microcline to muscovite.

(4) Final deformation after cessation of molybdenite mineralization resulting in slight slippage along the footwall fault, and further movement along the hanging wall fault producing gouge-filled seams darkened by a little molybdenite caught up during movements along this fault.

These various events were probably parts of a continuous process of deformation preceding, accompanying and postdating the introduction of the vein material.

La Corne Molybdenite Deposit.[6] The La Corne Molybdenite deposit[7] lies at the southwest corner of La Corne township about 19 miles south of east from Indian Molybdenum mine. A wide sand plain, in the vicinity of the deposit, conceals bedrock except at four small outcrop areas spaced at intervals of 1,000 to 2,000 feet apart along a narrow strip extending 5,000 feet

[6] Data, plans, and every facility for studying the La Corne deposit were very kindly placed at the writer's disposal by Mr. T. Fell, manager of the mine.

[7] Hawley, J. E.: Molybdenite deposits of La Corne township, Abitibi county. Quebec Bur. of Mines, Ann. Rept., part C: 97–122, 1930.

north. The outcrops indicate that directly south of the deposit a small mass of biotite granite at least 1,500 feet wide and 3,000 feet long extends northeast under the sand plain but the form and boundaries of this mass are very imperfectly known. Biotite schist with a series of intersecting cleavages striking northeast slightly divergently and dipping 60 to 70 degrees south flanks the north and south sides of the granite. The general strike of the contact of the biotite schist with greenstone about 4,000 feet west of the deposit is west of north, but the contact is perhaps crenulated due to drag folding, and dips steeply west.

The series of veins forming the deposit occur at the northwest side of the granite, and are partly exposed in a biotite schist outcrop about the mine shaft. Quartz veins, mostly under a foot wide containing minor amounts of molybdenite, occur also in the other outcrops in the sand plain and have the same general trends as those at the deposit. The biotite schist-granite contact at the deposit strikes about 45 degrees east of north and dips 70 degrees northwest. It is not a sharply definable feature, however, on account of numerous parallel granite dikes 1 to 20 feet wide cutting the schist in a zone 100 feet wide along the contact.

The principal veins at the deposit have two trends, one slightly north of east and the other west of north. The easterly veins form an en echelon series stepping east, northeastward, and extend from the biotite schist across the contact into the granite. They maintain fairly regular widths ranging from 1 to 7 feet throughout their length, particularly in the schist, and dip about 60 degrees south. The northerly veins occur only in the granite and end at the contact. They are lenticular and expand from narrow widths to 14 feet in places and dip very steeply or vertically.

The easterly veins consist of quartz margined on either side by zones a few inches to a foot wide containing much white feldspar (plagioclase) in the schist and muscovite in the granite. Molybdenite is concentrated in the marginal feldspathic and micaceous zones and also in aggregates of muscovite that form bunches 6 inches to 1 foot in diameter at widely spaced intervals in the interior of the veins. Besides molybdenite the veins contain minor amounts of pyrite, and more rarely bismuth, bismuthinite, chalcopyrite and columbite.[8] Conspicuous amounts of tourmaline and beryl are present in some veins and a little scheelite occurs rarely.

The northerly veins consist of quartz, red feldspar (microcline and albite), muscovite and molybdenite. Quartz in these veins occurs as irregular seams and lenses alternating with successive and narrower bands of red feldspar and muscovite along which molybdenite is concentrated. The feldspar-mica bands are considerably sheared out and show slickensided surfaces, which developed later than the molybdenite. The molybdenite content of these veins is higher than that in the easterly veins. This is shown in the results of assays given by Hawley [9] which were .43 and .52 per cent molybdenum in easterly veins, and 1.01 per cent molybdenum in one northerly vein.

[8] Hawley, J. E.: op. cit., p. 116.
[9] Op. cit., p. 121.

The similarity of the mineralogy of the La Corne and Indian Molybdenum deposits, their location at granite contacts, and the wide distribution of associated quartz veins controlled by a definite fracture pattern at these two localities suggest a similar mode of origin. Regarding the origin of the La Corne deposits Hawley [10] states

> fracturing and faulting continued throughout the intrusive granite over some period of time. This is best related to the cooling down of the intrusive and was accompanied by the injection of the quartz and pegmatite veins, with molybdenite. . . . Still later faulting occurred after the veins were formed, rendering some of them of little value.

The regional structure in the vicinity of the deposit is a drag fold that plunges steeply southwest and it seems probable that both the intrusive granite mass, which may be a sill or a stock, and the vein system of the deposit should have a similar plunge. It seems probable, however, that some local structure, either a warping of the granite contact or a fault zone, as at Indian Molybdenum mine, controls the local concentration of molybdenite-bearing veins at the La Corne deposit.

SUMMARY AND CONCLUSIONS.

Three pegmatite phases, representing successive stages in differentiation, are closely associated with biotite-muscovite granite masses in the Preissac-La Corne area.

The earliest phase consists chiefly of quartz, perthite, and muscovite with a little garnet. These pegmatites are, in part, irregular in outline and formed without any clearly defined structural control except such afforded by the exterior margins of the granite masses in which they occur and toward which they are concentrated.

The succeeding pegmatite phase is represented by types with a more complex mineral composition, including albite, tantalite-columbite, beryl, spodumene, molybdenite, with minute chrome spinel, and rarely phenacite.[11] These types in places are well banded. The tantalite-columbite and beryl-bearing pegmatites are restricted to the border zone of one large granite mass in the area and the spodumene-bearing varieties occur outside and east of this mass. This complex phase gave rise to a residual siliceous fraction that formed lenses and vein-like masses selvaged by muscovite along the centers of some of these dikes. Molybdenite, with bismuthinite and pyrite, was concentrated with this siliceous fraction which forms the final phase of the series.

The siliceous fraction appears as countless quartz and feldspathic quartz veins dissociated from more normal feldspathic pegmatites in the less deeply eroded muscovite-biotite granite masses of the area. The introduction of these veins was controlled by the fracture systems that developed in the upper cooled parts of these masses and by faults more particularly about their borders. The fracture systems developed probably in response to the cooling of the granite but with the faults were produced or activated during a period

[10] Op. cit., pp. 119–120.
[11] Bancroft, J. A.: Op. cit., p. 195.

of regional stresses whose existence is so clearly indicated by the highly folded structure of the district. The deformed character of the larger proportion of the molybdenite-bearing veins and the average higher content of molybdenite in the deformed veins indicates that the veins were introduced during a period of movement and stress conditions. Molybdenite is concentrated in veins near the margin of the granite masses, due probably to a drop in temperature, there, of solutions emanating from their interior at greater depths.

DEPARTMENT OF MINES AND RESOURCES,
OTTAWA, CANADA.
April 4, 1944.

A POLARIZED LIGHT COMPENSATOR FOR OPAQUE MINERALS.

A. F. TURNER, J. R. BENFORD, AND W. J. McLEAN.

ABSTACT.

The light reflected from anisotropic opaque minerals is rotated in azimuth and weakly elliptical when vertical illumination with polarized light is used. A compensator is described for analyzing this reflected light, particularly in combination with a full-aperture polarizing vertical illuminator. The compensator is traversed twice. It contains two measuring elements, one a mica plate to compensate ellipticity and the other an inclined thin film device to compensate rotation. The action of these elements is traced on the Poincaré sphere. Measurements on a series of opaque minerals, mostly uniaxial, were carried out with the compensator and the values of Berek's characteristic angle τ are reported. The polishing technique exerts a strong influence on τ; hence characteristic angle determinations may be used to determine the relative surface flow produced by each technique.

THE subject of quantitative measurements in polarized light reflected from opaque minerals has received little attention from American mineralogists. The general tendency has been to assume that, since polarization effects are small, they will not yield to quantitative measurements. This assumption appears incorrect. With appropriate equipment and technique reproducible quantitative measurements in polarized vertical illumination can be made on many opaque minerals. The development of this field promises to furnish the mineralogists with an important research and analytical tool.

In 1937 Max Berek treated the subject of such quantitative measurements very thoroughly and described a compensator suitable for use on an ore microscope.[1] However, his accessories are not adaptable to a full aperture vertical illumination system utilizing a calcite prism of the Foster design.[2] Since this system presents advantages over half-aperture illumination systems and is now in widespread use it seemed desirable to provide a compensator suitable for use in conjunction with it so that Berek's analytical methods might be applied. In the following such a compensator will be described, together with results obtained with it on both natural and polished faces of a short series of uniaxial opaque minerals.

Linear polarized light incident normally on an anisotropic opaque crystal is reflected in general as elliptically polarized light. Both a rotation and a phase retardation may be introduced by the reflection. Consequently such a specimen will become alternately light and dark when rotated on the stage with analyzer and polarizer crossed. Cubic crystals, on the other hand, do

[1] Berek, M.: Optische Messmethoden im polarisierten Aufllicht. Fort. der Miner. u. Petrogr. 22: 1, 1937.

[2] Foster, L. V.: Jour. Optical Soc. Am., Apr. 1938, p. 124.

not alter the state of polarization of the incident light and remain dark when rotated (assuming, of course, no scratch polarization). This distinction provides a ready qualitative method of assigning a specimen to one group or the other and is common practice. Further classification within the anisotropic group itself can then be made by determining the constants of the reflected elliptically polarized light to obtain a quantity τ, termed by Berek the "characteristic angle." This angle is essentially constant for any cut through a uniaxial crystal but varies from $-90°$ to $+90°$ for biaxial crystals, depending on the face under observation. Therefore, if two or more crystal cuts are available for measurement, uniaxial crystals can be distinguished from biaxial. The crystallographic orientation of the planes need not be known. If the crystal proves to be uniaxial the determination of the characteristic angle also serves to identify it mineralogically since the value of the angle varies from mineral to mineral within wide limits. Furthermore, conclusions can be reached regarding the orientation of the faces on which the measurements were made. Biaxial crystals can be identified satisfactorily only if the orientation of the face of the specimen be known.

As is to be expected, the polishing method exerts a strong influence on the measurements. The characteristic angle τ decreases as a flowed layer builds up so that it is possible to decide, on the basis of the measurements, which polishing technique gives results most nearly characteristic of the crystal uninfluenced by a flowed layer. Conversely, the flowed layer itself could be made the subject of investigation by means of the polarized light measurements.

In order to determine the constants of the reflected elliptically polarized light, two compensating devices are required: one to measure the phase shift, and one to measure the rotation of the plane of polarization. Ordinarily, the latter measurement is carried out by rotating the analyzer with respect to the polarizer but since this is not possible with the Foster prism, a separate rotation compensator is provided.

Figure 1 shows the optical system of the new compensator and Figure 2 is a photograph of the instrument in place under the stage of a Bausch & Lomb Research Metallographic Microscope, inverted type. Referring to Figure 1a, the Foster vertical illuminator prism of calcite acts as both polarizer and analyzer fixed in the crossed position. Since the beam dividing action of this prism is over the full aperture of the objective, a beam symmetrically disposed around the ray at normal incidence to the specimen is insured, a condition not realized with the half-aperture vertical illuminators in common use. This point is of importance in obtaining clear-cut measuring conditions. In the compensator unit itself, which is located directly above the vertical illuminator prism, there are two elements: a rotation compensator RC and an elliptical compensator EC. RC is a prism device and EC is a mica plate. Each is rotatable separately about the optical axis of the microscope and provided with a divided circle.

Rotation Compensator. The function of RC is to compensate any rotation of the plane of polarization caused by the specimen, by introducing an equal and opposite rotation. Half of this rotation is introduced into the up-

ward traveling incident beam, the other half into the downward traveling reflected beam. The compensator consists of two identical glass prisms cemented together with a transparent cement of the same index as that of the glass. On the inclined inner face of one prism is a quarter wave interference film with index differing from that of the glass. The compensator used in the measurements reported here is made of glass of refractive index 1.667. The film is of tin oxide, refractive index about 2.0, applied by high vacuum thermal evaporation. Other glass-film combinations are also practical.

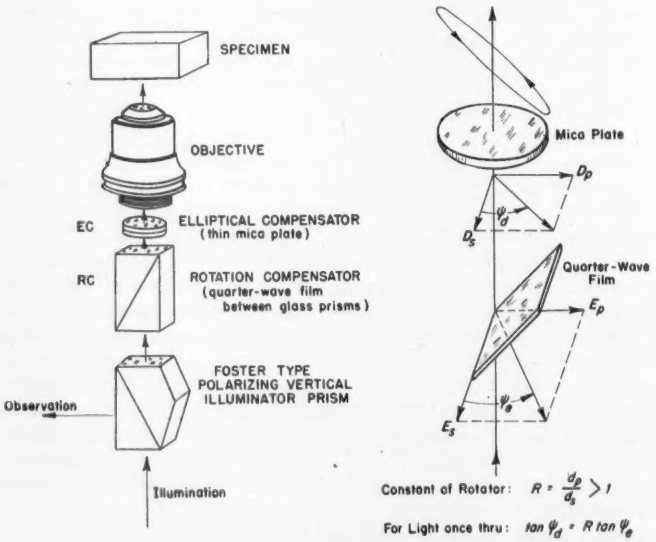

FIG. 1. (a) Elements of the optical system of the compensator. (b) Change in state of polarization of light *once* through the compensator. In use the light passes back through the compensator after reflection from the specimen.

The inclined film of the rotation compensator transmits the p-component of incident polarized light more copiously than the s-component (Fig. 1b). Consequently, the film rotates the azimuth of polarized light traversing it. This action is analogous to that of a simple inclined glass plate [3] but multiple images from the two surfaces of a glass plate render it useless in the present application. An interference film eliminates multiple images because rays reflected from its two surfaces are coherent and form but a single image. The optical thickness of the film was made one quarter wavelength of blue-green light for an angle of incidence on the film of 66° as determined by the prism angles. The quarter wave thickness gives a maximum rotation effect.

[3] Wood, R. W.: Physical Optics. Macmillan Co., N. Y. Orig. Edit., p. 236; 3rd Edit., p. 334.

Although the film can have this thickness for only one wavelength, experience has shown that if this position is near the center of the visible spectrum the rotation compensator will function satisfactorily in white light, as well as monochromatic light, when appropriate corrections are made.

The azimuthal rotation produced by one traversal of light through the inclined film may be expressed as follows:

$$\tan \psi_d = R \tan \psi_s \tag{1}$$

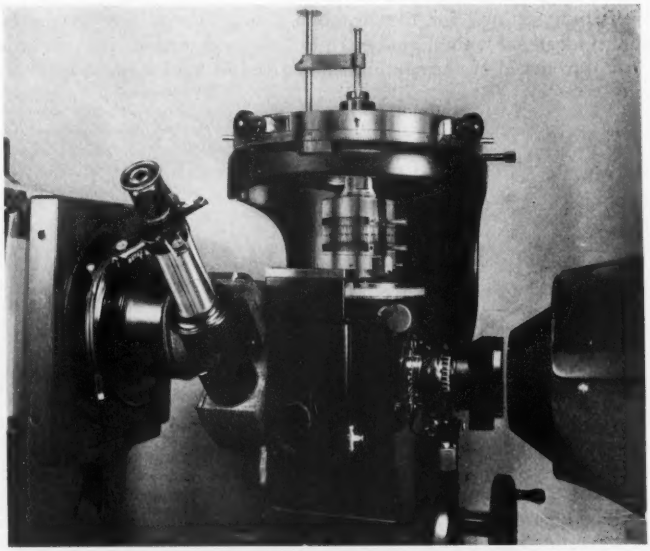

FIG. 2. Compensator unit in place under the stage of an inverted type microscope (Bausch & Lomb Research Metallographic Microscope).

where ψ_c is the azimuth of the plane polarized light incident on the prism referred to the *s*-vibration direction (at right angles to the plane of incidence), ψ_d is the azimuth of the transmitted light and R is the ratio of the amplitude transmittances of the film (see fig. 1b): That is:

$$R = \frac{d_p}{d_s} \tag{2}$$

where d_p and d_s are the p and s amplitude transmittances of the film.

Disregarding the Mica Elliptical Compensator for the moment, the azimuth of the light incident on the specimen will be ψ_d but the reflected light will have a different azimuth ψ_c' if the specimen produces rotation. ψ_c' will in turn be the azimuth of the light incident on the rotation compensator in the return

direction. The second passage of the light through the inclined film produces a second rotation which, by Equation (1), is in the same sense as the first. Finally the azimuth upon emergence from the prism will be ψ_d', where

$$\tan \psi_d' = R \tan \psi_e' \tag{1a}$$

In use, the compensator is turned about the optical axis of the system until extinction, that is, compensation, is found. Bearing in mind that polarizer and analyzer are crossed due to the construction of the Foster prism, it will be clear that compensation occurs when $\psi_d' = \psi_e \equiv r$, r being defined as the "compensation setting" for the Rotation Compensator. By means of this condition, together with Equation (1), the expression for the rotation $(\psi_d - \psi_e')$ produced by the specimen is derived in the following manner:

$$\tan (\psi_d - \psi_e') = \frac{\tan \psi_d - \tan \psi_e'}{1 + \tan \psi_d \tan \psi_e'} = \frac{R \tan r - \dfrac{\tan r}{R}}{1 + \tan^2 r}$$

$$= \frac{R^2 - 1}{R} \frac{\tan r}{\sec^2 r} = \frac{R^2 - 1}{2R} \sin 2r$$

or defining ϵ as the quantity $\tan (\psi_d - \psi_e')$:

$$\epsilon = \frac{R^2 - 1}{2R} \sin 2r \tag{3}$$

The compensator used had a measured constant $R = 1.101$ for Hg green 5461 Å, hence the maximum rotation $(\psi_e' - \psi_d)$ of the plane of polarization by the specimen which could be compensated was about 5.4° for a 45° rotation r of the compensator. The compensator acts effectively as a "slow-motion" rotating polarizing prism with a step down ratio of about 8:1. This gives the measurement of rotation a high sensitivity, which is important since the rotation of the plane of polarization by opaque minerals is invariably a small amount, generally less than 5°.

Elliptical Compensator. The ellipticity due to the reflection from the mineral specimen is measured by an extremely thin mica plate, the "Elliptical Compensator," located above the Rotation Compensator (Fig. 1). This plate is cemented between cover glasses and is rotatable in its own plane. The light traverses it in both the incident and reflected directions. The phase shift which the mica introduces into the beam must be equal and opposite in sign to that of the specimen. Half of this compensating phase shift is put into the beam in the incident direction, the other half on the return through the mica. The action of the plate can best be understood by reference to a surface known as "Poincaré's Sphere." [4]

Since the Poincaré Sphere does not seem to be as well known as its simplicity and usefulness entitle it to be, a brief description of what it is and the rules for applying it will be given here.

Figure 3 illustrates the general use of the Poincaré Sphere construction in designating the particular state of an elliptical vibration. Each point of the

[4] Skinner, C. A.: Jour. Optical Soc. Am. 10: 491, 1925.

surface describes the parameters of an elliptical vibration. Points on the equator of the sphere represent linear vibrations, and the poles represent circular vibrations (the two limiting forms of the ellipse). Points of the northern hemisphere represent counter-clockwise ellipses and points of the southern hemisphere clockwise ellipses by convention. A given rotation 2ψ of a point Q, indicates a change in azimuth of the vibration by half this amount, *i.e.*, by an angle ψ. Thus, points Q and R represent linear vibrations whose azimuths differ by an angle ψ. In general, the *longitude* of any point on the sphere measured from a given reference meridian is *double* the

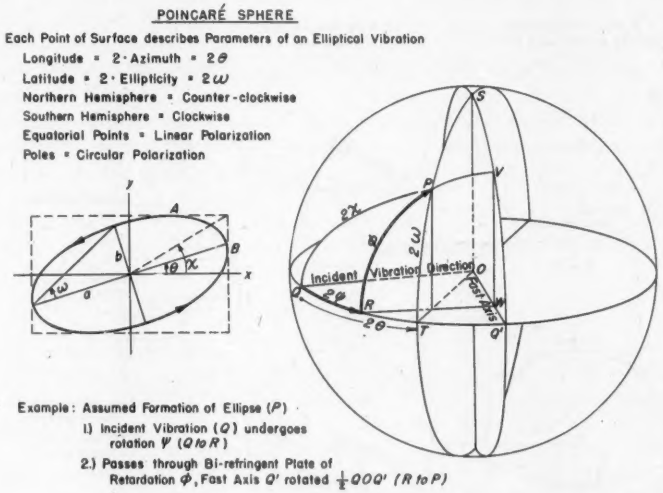
POINCARÉ SPHERE
Each Point of Surface describes Parameters of an Elliptical Vibration
Longitude = 2·Azimuth = 2θ
Latitude = 2·Ellipticity = 2ω
Northern Hemisphere = Counter-clockwise
Southern Hemisphere = Clockwise
Equatorial Points = Linear Polarization
Poles = Circular Polarization
Example: Assumed Formation of Ellipse (P)
1) Incident Vibration (Q) undergoes rotation Ψ (Q to R)
2) Passes through Bi-refringent Plate of Retardation Φ, Fast Axis Q' rotated ½QOQ' (R to P)
Incident Vibration Direction
Fast Axis

FIG. 3. Representation of an elliptical vibration on the Poincaré Sphere.

angle between the plane of the major axis of the ellipse and the plane of the reference meridian. The latitude of any such point is equal to the angle 2ω where

$$\tan \omega = \frac{b}{a} \tag{4}$$

a being the major and b the minor axis of the ellipse. Hence, the latitude and longitude of any point on the sphere completely identify the state of polarization of the light.

To visualize now the effect of a rotation as introduced by RC as well as a phase shift as introduced by the birefringent plate in EC call the latter's phase retardation ϕ, and assume the fast axis of the plate makes an angle m with reference to the vibration direction of the incident light. On the sphere, Figure 3, one represents the fast axis as a point on the equator located at an

angle $2m = QQ'$ with reference to the meridian of the point Q representing the incident light. The effect of passage of this light in one direction only through the two elements of the compensator is represented respectively by a rotation from Q to R about the polar axis followed by a clockwise rotation through an angle ϕ from R to P about the equatorial line OQ' representing the fast axis of the plate.

The complete change in the state of polarization of the light as it passes through RC and EC, is reflected from the specimen, and then returns through the system can be depicted as the path of a point on the surface of the Poincaré Sphere (Fig. 4). The five successive steps are shown for the case

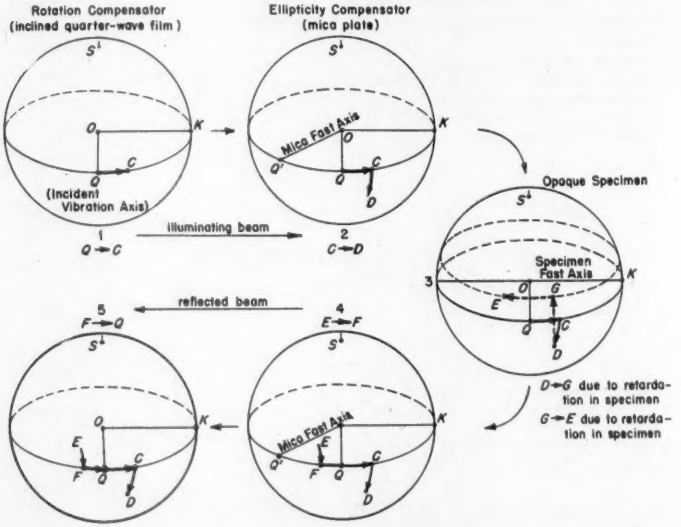

FIG. 4. The 5 vibration states during the passage of light through the compensator as represented on the Poincaré Sphere.

in which the compensator elements are set to compensate both the phase shift and rotation introduced by the specimen. In (1) the original linear polarized light Q from the polarizer is rotated by its passage through the rotation prism. This is represented by displacing the point from Q along the equator to some new position C. The light then traverses the mica compensator in (2) and the point moves from C to D, rotating around $Q'O$ representing the fast axis of the mica plate. Reflection from the specimen results in both a phase displacement and a rotation, represented respectively by a displacement of the point from D to G and from G to E in (3). In passing back through the mica compensator, the point moves from E to F in (4). The final passage through the rotation prism then returns the point to Q as shown in (5). This is the necessary condition for compensation, the criterion for

which is the complete extinction by the analyzer of the light emerging from the compensator. Since with the Foster type prism analyzer and polarizer effectively are crossed, complete extinction of the light reflected from the specimen is obtained only when the light is linearly polarized in the same azimuth as the incident light. In other words on the Poincaré Sphere the point must return to its initial starting point Q after traversing the complete compensator-specimen system.

One can show by projection geometry, taking the projection view in the direction OQ (Fig. 4), that the phase difference Δ of the specimen is expressed by the relation:

$$\sin \Delta = \sin \phi[\sin (2m + 2d_1) + \sin (2m - 2d_2)] \tag{5}$$

where ϕ is the phase retardation of the mica plate EC, m is the angular displacement of EC from its zero position, d_1 and d_2 are the individual rotations of the plane of polarization by the rotation compensator in the incident and the reflected beams respectively. The fast axis of the specimen is understood to be at 45° to the plane of polarization of the polarizer; hence on the sphere, it is represented as a direction 90° from OQ.

This formula can be simplified by making use of the fact that d_1 and d_2 are small and approximately equal angles and that Δ is also small. We obtain then from (5) as a sufficiently good approximation:

$$\Delta = 2 \sin \phi \sin 2m \tag{6}$$

Δ being expressed in radians.

The Characteristic Angle. In applying Berek's Theory to the examination of opaque minerals, the determination of the "Characteristic Angle" τ by means of the compensator is of prime interest. This angle τ is the phase shift, imparted by the reflection at the specimen, between light vibrating parallel and perpendicular to the vibration direction of the *polarizer*. The specimen is assumed in the diagonal position. For linear polarized incident light, the reflected ellipse can be written in the form

$$\nu e^{i\tau} = \epsilon + i\delta \tag{7}$$

directions being referred to the vibration direction p of the polarizer and to a vibration direction s normal thereto.

It can be shown for the case of a very narrow ellipse, as is always encountered in this work, that ϵ is the tangent of the azimuth referred to the p direction and δ is the ratio of the minor to the major axis of the ellipse. Berek terms ϵ the "polarization coefficient" and δ the "phase coefficient." From Equation 7 it follows that

$$\tan \tau = \frac{\delta}{\epsilon} \tag{8}$$

The characteristic angle can also be expressed in terms of the specimen phase shift Δ defined in Equation (6). Since the polarization coefficient δ of the reflected ellipse is equal to the axis ratio and this in turn is the tangent of

one-half the latitude of the point on the Poincaré Sphere, it follows, for the small angles involved, that

$$\Delta = -2\delta \tag{9}$$

the minus sign arising from the convention of signs on the sphere. Accordingly

$$\tan \tau = \frac{-\Delta}{2\epsilon} \tag{10}$$

The unique point about the characteristic angle τ is the fact that for uniaxial crystals, it is very nearly constant, independent of the cut of the face. For uniaxial crystals τ can, therefore, aid in identification. For biaxial minerals τ varies between $+90°$ and $-90°$, depending on the plane of section.

Any tendency of the polishing technique to create a flowed amorphous surface layer over the crystalline structure of the mineral is revealed by a decrease in the value of τ.[5] That particular polishing technique which yields the highest value of τ comes nearest to presenting the true appearance of the crystalline structure in polarized light, unobscured by any amorphous film on the polished surface. Thus the measurement of τ serves as a criterion of the excellence of the polishing technique. Fresh cleavage surfaces invariably yield the highest value of τ, and this value may be taken as a maximum to be striven towards in polishing.

From Equations (3), (6), (10), the tangent of the characteristic angle of the mineral face, expressed in terms of the rotation and elliptic compensator settings, r and m respectively, is [6]

$$\tan \tau = \frac{-\sin \phi \sin 2m}{\frac{R^2 - 1}{2R} \sin 2r} \tag{11a}$$

To this must be added a small correction term which is due to an "elliptic defect" of the rotation prism. For all wavelengths except the one where the inclined film is exactly a quarter wavelength thick the p and s components suffer a relative phase change. On the long wavelength side of the quarter wave position the rotation prism acts as a weakly birefringent plate with its slow axis in the s direction; on the short wavelength side, it acts as a plate with its slow axis in the p direction.

At the wavelength for which the interference film is exactly one-quarter wave thick (optically) this defect disappears. The effect of this phase shift in the rotation prism must be added to that of the mica plate in the numerator of Equation (11a) which then becomes

$$\tan \tau = \frac{-\sin \phi \sin 2m + \sin \rho \sin 2r}{\frac{R^2 - 1}{2R} \sin 2r} \tag{11}$$

[5] Berek, M.: op. cit., pp. 94–101.

[6] Strictly speaking τ here is not exactly equivalent to Berek's τ due to the fact that in the present compensator the light incident on the specimen is already partially "compensated." For practical purposes, however, the two τ's may be assumed equal.

where ρ is the phase retardation angle of the rotation prism, analogous to ϕ of the mica plate.

The quantities ϕ, ρ, and R can be determined experimentally. Stokes' method was used in the determination of the retardation ϕ of the mica plate. The mica plate was then in turn used to measure ρ of the rotation compensator according to Berek's method. This was verified by a measurement using Stokes' method. R was determined by measuring directly the rotation produced by the rotation prism located between a polarizer and an analyzer. Each of these quantities depends on the wavelength of the light used. The following values were obtained:

λ	ϕ	ρ	R
5461 Å	6.36°	1.30°	1.101
White Light (Carbon Arc)	5.24°	1.42°	1.096

The quarter wave thickness position of the rotation prism used was in the blue-green, hence R decreases and ρ increases as one goes from green to the white light of the carbon arc, the center of gravity of the latter being toward the red from the mercury green line. A rotation prism having a somewhat thicker film to displace the quarter wave position toward the green would result in a smaller correction and in this respect would be preferable to the sample used.

When the above values are inserted in Equation (11); one obtains

$$\text{For 5461 Å:} \qquad \tan \tau = -1.150 \frac{\sin 2m}{\sin 2r} + 0.235 \tag{12}$$

$$\text{For White Light:} \quad \tan \tau = -0.992 \frac{\sin 2m}{\sin 2r} + 0.270 \tag{13}$$

These were the working formulae used in the measurements reported below.

Measuring Procedure. Measurements with the compensator are carried out in the following manner: (*a*) An optically inactive specimen, for example, silver, stellite, or pyrite, is placed on the stage and the compensator elements *EC* and *RC* alternately rotated until the specimen appears darkest, (*b*) the optically inactive specimen is removed and replaced by the specimen to be measured, (*c*) this specimen is rotated to its darkest position and the stage divided circle reading noted, (*d*) the stage is then rotated (approximately 90°) to the next position of darkness and its reading again noted, (*e*) the numerical average of these two readings is the diagonal position at which the specimen is next set, (*f*) the compensator elements are alternately rotated until the specimen becomes darkest, the divided circle readings being tabulated as m_1 and r_1, (*g*) the specimen is then rotated 90° and (*h*) the compensator elements again adjusted to make the specimen appear darkest, these readings

being tabulated as m_2 and r_2. These values are inserted in Equation (12) and (13) using the following relations:

$$m_1 - m_2 = 2m$$
$$r_1 - r_2 = 2r$$

Steps (*e*), (*f*), (*g*), and (*h*) on a specimen of niccolite are shown in Figure 5. The specimen area being compensated in these photographs is the crystal

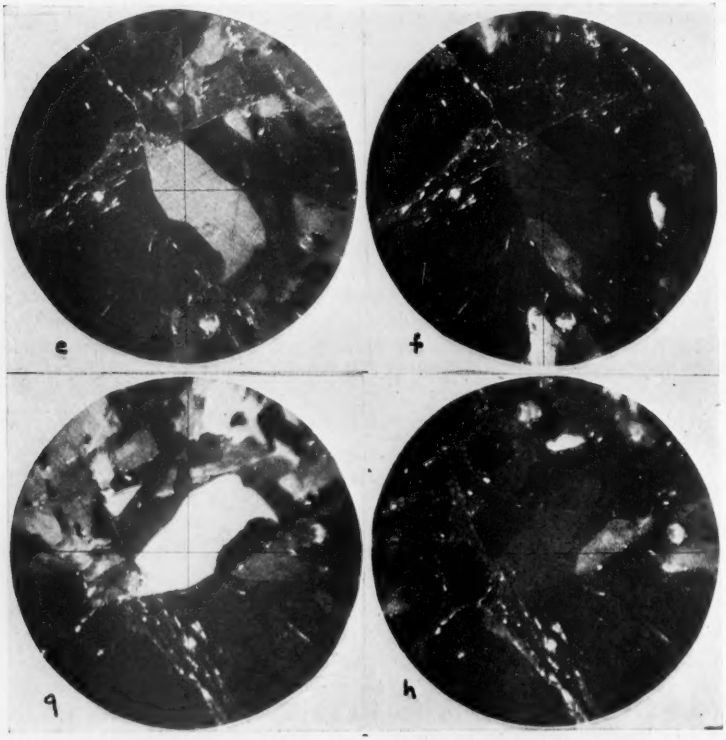

FIG. 5. Appearance of a niccolite specimen during compensation.

which is on the cross line in the center of the picture. Incidentally, Figure 5 (*g*) shows that the contrast of a weakly anisotropic crystal against its background can be accentuated by setting the compensator elements in such a manner as to add to the effects of the specimen, *i.e.* by compensating in one diagonal position and then rotating the specimen to the other diagonal position.

Results of the Measurements. Table 1 gives the results of measurements of τ on various uniaxial minerals. In all cases the minerals were unetched. Wherever possible, results on crystalline faces are included. A 16 mm. microscope objective and a 5X Huygens Eyepiece were used for most of the

TABLE 1.

Specimen.	Illum.	Surface Preparation.	τ	No. of Observations.
Hematite from Elba	Carbon Arc	Aver. of *5* Crystal Faces	$-13.7° \pm 2.4°$*	25
		Hard Pitch, chrome oxide	$-13.9° \pm 2.1°$	18
		Soft Pitch, chrome oxide	$-15.6° \pm 3.2°$	21
		Lead Lap, chrome oxide	$-14.9° \pm 4.6°$	45
		Cloth wheel, levigated alumina	$-17.9° \pm 4.2°$	36
Niccolite, from Cobalt, Canada	5461 Å	Hard Pitch, rouge	$31.9° \pm 2.8°$	9
		Hard Pitch, chrome oxide	$44.6° \pm 3.9°$	15
		Soft Pitch, rouge	$36.3° \pm 3.0°$	9
Same, but new specimen	5461 Å	Hard Pitch, chrome oxide	$36.7° \pm 3.7°$	51
Niccolite, from Eisleben, Thuringia	5461 Å	Hard Pitch, chrome oxide	$36.6° \pm 3.5°$	15
		Hard Pitch, rouge	$33.1° \pm 2.8°$	6
Proustite, from Hungary	Carbon Arc	Aver. on *2* Crystal Faces	$-43.2° \pm 2.1°$	18
Heterolite, from New Jersey	5461 Å	Hard Pitch, chrome oxide	$-10.1° \pm 2.3°$	36
		Cloth wheel, levigated alumina	$-17.1° \pm 4.0°$	27
Ilmenite, from Kragero, Norway cut parallel to axis	5461 Å	Hard Pitch, chrome oxide	$-16.9° \pm 2.2°$	21
		Cloth wheel, levigated alumina	$-16.7° \pm 2.8°$	27
Same, but cut at 45° to optic axis	5461 Å	Hard Pitch, chrome oxide	$-19.7° \pm 3.6°$	18
		Cloth wheel, levigated alumina	$-26.0° \pm 5.3°$	18
Cassiterite, from Salamanca, Spain	5461 Å	Crystal Faces	$-10.8° \pm 6.2°$	18
Cassiterite, from Nigeria, Africa	5461 Å	Crystal Faces	$-14.9° \pm 2.4°$	18
Cassiterite, from Storey's Creek, Tasmania	5461 Å	Crystal Faces	$-13.6° \pm 8.1°$	6
		Hard Pitch, chrome oxide	$-17.8° \pm 8.7°$	75
		Cloth wheel, levigated alumina	$-25.9° \pm 4.5°$	30
Pyrargyrite, from Juanajuato, Mexico	5461 Å	Crystal Faces	$-32.1° \pm 3.3°$*	25
Anatase, from Brazil	5461 Å	Crystal Faces	$-25.8° \pm 10.6°$*	20
Rutile, from Georgia	5461 Å	Crystal Faces	$-15.2° \pm 1.7°$*	25

measurements. For isolating very tiny crystals the 5X eyepiece was replaced by the 10X sliding-stop eyepiece shown in Figure 2. In the last column of Table 1, is the number of observations on which the value of τ is based. By an observation we mean a single setting of each element of the compensator on each side of its zero setting. In all cases except those

marked with an asterisk, the plus and minus terms indicate the average deviation from the mean for a group of three observations. Those marked with an asterisk are based on groups of five observations.

An interesting example of the measurements on which Table 1 is based occurred in the case of the mineral ilmenite, from Kragero, Norway. The specimen, when first mounted and polished showed no evidence of anisotropy. We believed the direction of cut was by chance approximately perpendicular to the optic axis, and acting on this hypothesis cut one piece of the specimen at 45° and another at 90° to the original direction. The two pieces were mounted side by side in bakelite and given the same polishing treatment after which both new sections showed measurable anisotropy. Sample measurements were as follows:

TABLE 2.

ILMENITE.

Specimen Cut.	Illum.	Polish.	m_1	r_1	m_2	r_2	$2m$	$2r$	τ
Specimen cut approx. parallel to optic axis	5461 Å	Hard pitch	92.8°	95.3°	81.8°	74.2°	11.0°	21.1°	−20.5°
Specimen cut approx. at 45° to optic axis	5461 Å	Hard pitch	89.8°	90.1°	84.0°	78.3°	5.8°	11.8°	−18.4°

These measurements indicated that our hypothesis on the original cut of the ilmenite was correct. They were of interest because they demonstrated how the values $2m$ and $2r$ varied with the direction of the cut, being considerably greater for the cut parallel to the optic axis, and yet despite almost a 2 to 1 variation in these values, the two values of the characteristic angle τ are not greatly different.

It is interesting also to observe the much greater accuracy in the determination of τ for rutile than for anatase. The reason for this lies in the numerical values of $2m$ and $2r$ being much greater in the case of Rutile than in that of Anatase. Anatase was the most difficult mineral to measure yet encountered, because both the ellipticity and rotation were so small.

In Table 1, the results obtained in monochromatic green light 5461 Å are probably more reliable than those measured in white light, since they are less dependent on the observer's judgment and the normalcy of his color vision.

There is in many cases a definite dispersion of τ with wavelength, which might be used as a further check in identifying a mineral. For example, if two minerals give approximately the same value of τ at 5461 Å, a second measurement at another wavelength in the mercury spectrum, *e.g.* the 4358 Å blue line, could be used as a double check on the identity. If the minerals are not identical they possibly would not have identical values of τ at both wavelengths, and could be differentiated.

The measurements in Table 1, especially those on hematite, show how different polishing techniques produce different results. The hard pitch polish gives not only the highest value of τ (in the positive sense) but also

the most consistent results, and is accordingly judged to be the best of the four methods tried on hematite. This dependence of the results on the polishing method shows how the compensator can be applied as a means of studying any new polishing technique.

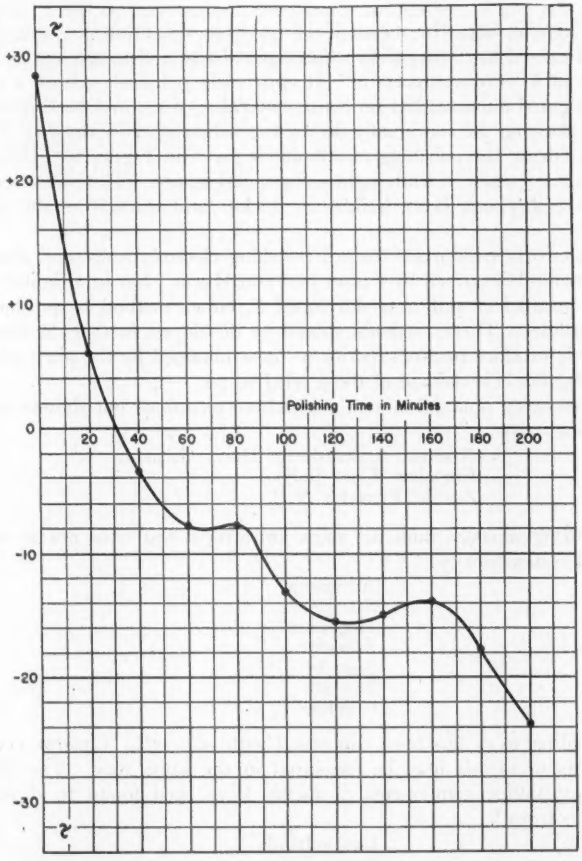

FIG. 6. Formation of a flowed surface layer on stibnite due to polishing.

Some work was also done on the soft biaxial mineral stibnite. Stibnite gives such excellent lamellar cleavage that measurements on the cleavage faces can well serve as calibration measurements. We obtained as an average

of 24 measurements in white light:

$$\tau = 28.4° \pm 2.1°$$

and as an average of 30 measurements in mercury green light, 5461 Å:

$$\tau = 25.1° \pm 0.7°$$

The ± term is here the mean deviation from the mean for a group of *3* observations. Efforts to polish stibnite parallel to a cleavage face using hard and soft pitch were unsuccessful. It apparently polished well on a cloth lap using levigated alumina, but no consistent value of τ could be thus obtained. A graph showing the continually decreasing values of τ, obtained at 20 minute intervals during the polishing of stibnite is given in Figure 6. These measurements were made in white light using a carbon arc. The indication is that a flowed amorphous layer builds up thicker and thicker as the polishing proceeds.

Some efforts were made toward polishing electrolytically and also by the dry lap method described by Fraser and von Huene,[7] but in a limited amount of time, insufficient skill was developed at either method to produce satisfactory results. These methods should be developed further, as they could conceivably produce results superior to those obtained by the pitch polish, the latter being the best method of those tried so far.

The following uniaxial minerals have been examined but showed no measurable anisotropy:

Arsenic, Andreasburg, Harz, Germany
Cinnabar, Ripa, Italy
Zincite, Franklin, N. J.

The following uniaxial minerals show anisotropy, but have not as yet been measured systematically:

Antimony
Stannite
Hogbomite
Scheelite
Siderite
Bismuth
Graphite

The preceding work has been concerned with *minerals*. Opaque crystalline components of *metals* may be measured in the same way. The following uniaxial crystalline components of metals have been found to show measurable anisotropy:

Iron sulphide
Ferro-silicon
Ferro-manganese
$CuAl_2$
AlFeSi

Probably many more constituents amenable to such measurements are to be found in commercial metals.

[7] Fraser and von Huene: Amer. Min. 27: 261, 1942.

CONCLUSION.

An improved type of compensator for full-aperture polarization measurements on opaque anisotropic minerals has been described. It is suggested as a useful tool for differentiating biaxial and uniaxial opaque minerals, and for identifying minerals within the latter classification. The dependence of the results on the surface condition suggests application of the compensator to the testing of old or new polishing techniques and to the measurement of the rate of growth of oxidation films, etc., on freshly cleaved or polished crystals.

BAUSCH AND LOMB OPTICAL CO.,
ROCHESTER, NEW YORK,
May 17, 1944.

SCHEELITE IN NORTHEASTERN BRAZIL.

W. D. JOHNSTON, JR., AND FRANCISCO MOACYR DE VASCONCELLOS.[1]

ABSTRACT.

About 60 scheelite localities are now known in the States of Paraíba and Rio Grande do Norte, Northeastern Brazil, all of which have been discovered since early 1942, and production in the first 2½ years of the new district has been about 2,500 metric tons of 70 per cent WO_3 concentrates. The scheelite occurs in epidote-garnet-quartz tactites developed in calcareous layers interbedded in Pre-Cambrian mica schists near granitic intrusions. The region gives promise of becoming one of the world's important sources of tungsten.

INTRODUCTION.

SCHEELITE was discovered in Northeastern Brazil in early 1942,[2] and, by the end of 1943, at least 60 scheelite localities in the States of Paraíba and Rio Grande do Norte were known.[3]

Up to June, 1944, about 2,500 metric tons of scheelite concentrates containing over 70 per cent WO_3 had been produced, all by hand methods of mining and panning.

In late July and early August, 1943, we visited 25 mines and prospects in the area, which included the principal producing mines then known, and later published a brief description of them[4] in Portuguese. In March, 1944, Johnston revisited the area and made the accompanying sketch maps of four of the mines with the best production records up to that time. Brief descriptions of these mines were also published in Portuguese.[5]

The purpose of this paper is to summarize briefly, in English, the salient geological features of this new tungsten area. Other individual mine descriptions will be found in the Brazilian articles.

We are indebted to Dr. Sandoval Carneiro de Almeida, former chief of the Campina Grande station of the Departamento Nacional da Produção Mineral, who accompanied us during a part of our visit in 1943 and with whom Johnston had visited the Quixaba mine in June, 1942, and to Sr.

[1] Published by permission of the Director, Departamento Nacional da Produção Mineral, and the Associate Director, Foreign Procurement and Development Branch, Foreign Economic Administration.

[2] Othon H. Leonardos: Minérios de tungstênio no Brasil. Mineração e Metalurgia, vol. VI, pp. 238–239, 1942.

[3] Clarindo Rabello: Tungstênio na Paraíba e Rio Grande do Norte. Mineração e Metalurgia, vol. VII, pp. 137–139, 1943.

[4] W. D. Johnston, Jr., and Francisco Moacyr de Vasconcellos: Tungstênio na Paraíba e Rio Grande do Norte. Minerção e Metalurgia, vol. VII, pp. 247–260, 1943.

——: Divisão de Fomento da Produção Mineral, Avulso n°52, 1944.

[5] W. D. Johnston, Jr.: Barra Verde, Barro Vermelho, Bodó e Cafuca, minas de scheelita no Rio Grande do Norte. Mineração e Metalurgia, vol. VIII, n° 44, 1944.

Alexandre Leite de Barros, who assisted Johnston during the 1944 examination.

GEOLOGICAL ENVIRONMENT.

With the exceptions of a narrow coastal belt of Cretaceous and later sediments, the rocks of Northeastern Brazil belong to the crystalline complex of

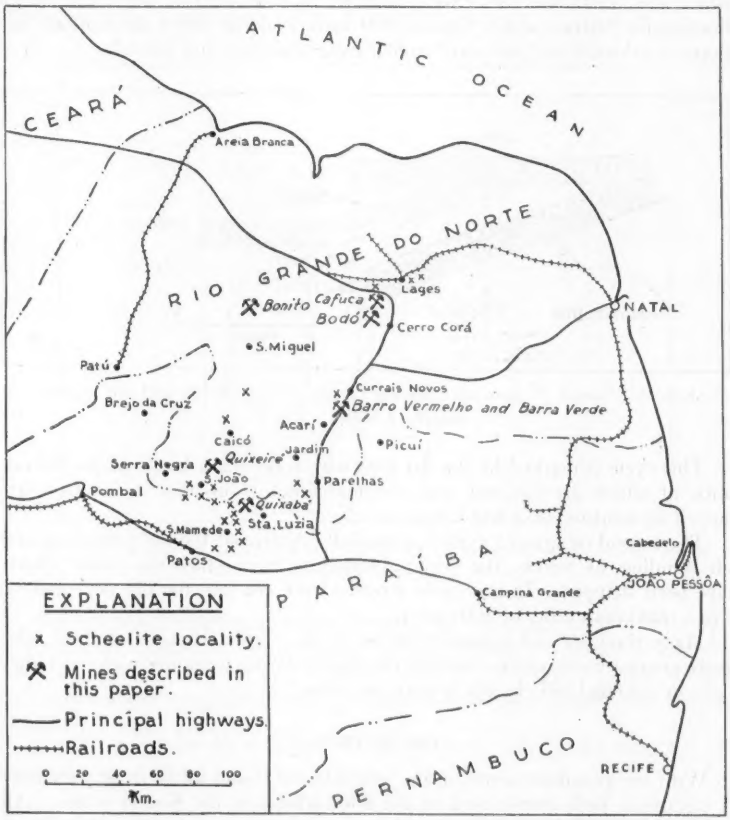

FIG. 1. Index map showing location of scheelite deposits.

the Brazilian shield. Mica schists, called the Seridó series by L. J. de Moraes,[6] with interbedded limestones, marbles, and quartzites have been intruded by great granite batholiths, followed by pegmatites, which yield im-

[6] Luciano Jacques de Moraes: Serras e Montanhas do Nordeste. Inspetoria Federal de Obras contra as Sêcas, Publ. 58, vol. 2, p. 49, 1924.

portant quantities of cassiterite, tantalite, and beryl,[7] and quartz veins. The mica schists were tightly folded, pure limestones were converted into marble and impure limestones into amphibolite. Many phenomena of contact metamorphism were developed in the older rocks, including limestones altered to scheelite-bearing tactites.

Two cycles of erosion are conspicuous in the region. An older cycle in which the crystalline rocks were reduced to base level is preserved in the Borborema Plateau which rises to 700 meters in the Serra da Santana and slopes southward and eastward to 550 meters at Campina Grande.

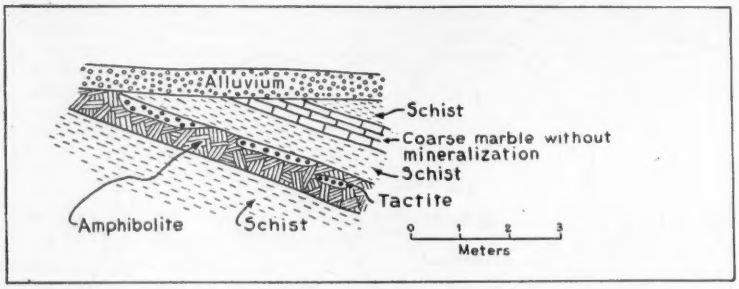

FIG. 2. Sketch of open cut showing tactite in amphibolite and not in pure marble, Caieira mine.

This cycle is marked by the flat tops with concordant levels of the Serras, some of which are covered with residual limonite nodules and others are capped by sandstones of late Cretaceous age.

The second or present cycle has partially destroyed the old peneplane and left standing, as Serras, the granite batholiths from which the softer schists have been stripped. In this cycle streams have cut into the old peneplain to give a maximum relief of 500 meters.

Many thousands of pegmatite dikes in the region, because of their relatively greater resistance to erosion, rise above the surrounding rocks as either walls or rounded hills locally known as "altos."

ORE DEPOSITS.

With one possible exception, the scheelite ore bodies all lie in or very near to calcareous beds intercalated in the mica schists of the Seridó series. All are marked by the presence of epidote, garnet, or quartz. One or more of these minerals may serve as guides to ore.

[7] Sandoval C. de Almeida, W. D. Johnston, Jr., Evaristo P. Scorza, e Othon H. Leonardos: Pegmatitos com berilo, tantalita, e cassiterita da Paraíba e Rio Grande do Norte. Mineração e Metalurgia, vol. VII, pp. 115–126, 1943.

——: The beryl-tantalite-cassiterite pegmatites of Paraíba and Rio Grande do Norte, Northeastern Brazil. ECON. GEOL., vol. 39, pp. 206–223, 1944.

Evaristo Penna Scorza: Província pegmatítica da Borborema. Divisão de Geologia e Mineralogia, Bol. 112, 1944.

The calcareous beds range from pure crystalline marbles to amphibolites. In general, where a pure marble and a clayey marble or an amphibolite occur close together, it is the impure marble or the amphibolite that is mineralized (Fig. 2).

In wider calcareous beds the strongest mineralization generally is in the marble or amphibolite in contact with the enclosing mica schist; indeed a schist contact appears to be a necessary requisite for mineralization in the wider and purer marble beds (Figs. 3, 4 and 8).

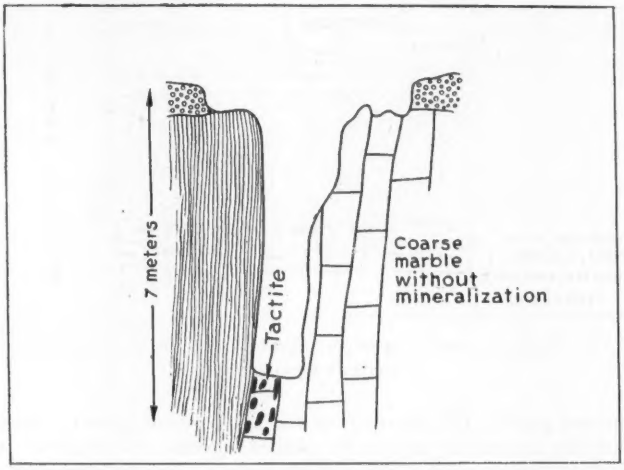

FIG. 3. Sketch of south cut of Barra Verde mine showing tactite zone on schist contact.

The marbles are generally coarsely crystalline and range in color from pure white to grey to salmon. Most contain minute crystals of pyrite and graphite, and, when freshly broken, give a strong odor of hydrogen sulphide. These substances are most probably relics of organic material originally contained in limestone beds.

Quartz veins also carry scheelite, but generally only when they cut calcareous rocks (Fig. 5).

Mineralogy.

The principal contact metamorphic minerals developed in the limestones of the region are epidote, garnet, and quartz. Vesuvianite, wollastonite, hornblende, scapolite, and scheelite are wide-spread but less abundant. Molybdenite has been found in several mines [8] and a few tons of bismutite have been recovered from scheelite placers.

[8] Paulo Anibal Marques de Almeida Rolff: Molibdenita na Paraíba e no Rio Grande do Norte. Mineração e Metalurgia, vol. VII, p. 357, 1944.

Andradite garnet forms distinct crystals as well as irregular aggregates of crystals in the calcareous beds. Although garnet and epidote usually occur together, at some mines, such as the Caieira, epidote is rare and garnet is the

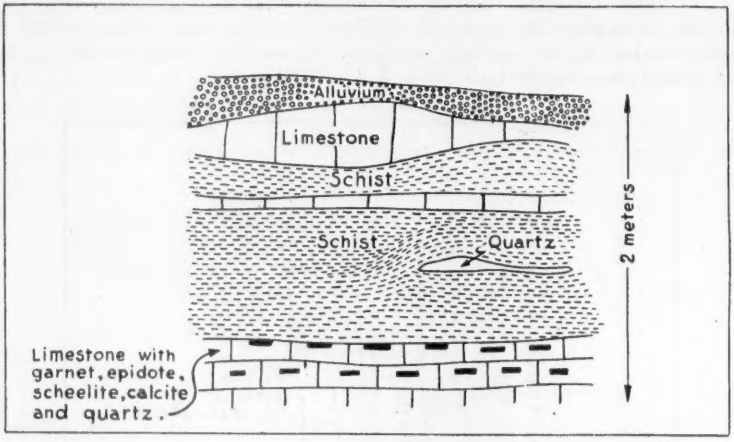

FIG. 4. Sketch of wall of open cut showing tactite on the schist contact, Vereda do Meio mine.

dominant ore guide. Elsewhere, as at the Bonito mine, garnet is rare, and is formed only in small crystals in the panned scheelite concentrates.

Epidote is present in all of the scheelite deposits. In the calcareous rocks that have not been strongly silicified it occurs in small crystals or fine grained masses, whereas in highly silicified beds it forms large flat plates.

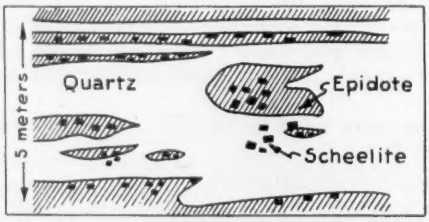

FIG. 5. Sketch of outcrop of quartz-epidote tactite, Bonito mine.

Quartz is also an ore guide, ranking in importance with garnet and epidote. It may replace limestone, or have the form of lit-par-lit lenses in schist as at the Riacho Fechado mine (Fig. 6). Quartz veins are to be seen at most of the mines and prospects, and many of these veins carry scheelite.

Scapolite occurs in short stubby prisms, wollastonite and hornblende in fibrous aggregates, and vesuvianite in characteristic tetragonal prisms.

Scheelite generally occurs in crystals less than 1 cm. in diameter and the average size is near 1 to 2 mm. At some mines, however, crystals weighing 500 grams to 1 kilogram are not uncommon. The largest piece of scheelite that we saw was a part of a crystal from the Barro Vermelho mine weighing 2.2 kilos.

Generally the scheelite of the region is white to light gray in color; but it may be dark gray to dark green.

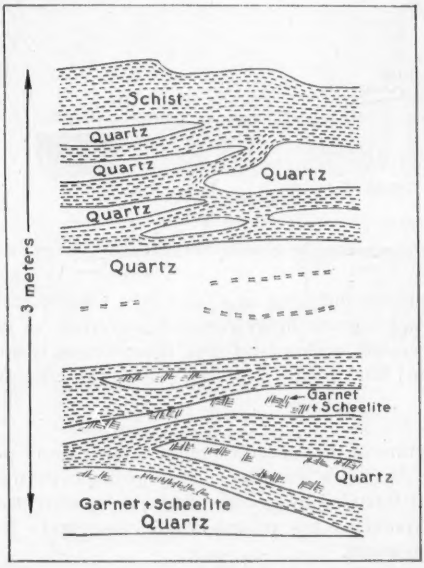

FIG. 6. Sketch of open cut showing silicified limestone with garnet and scheelite, Riacho Fechado mine.

The fluorescent colors, under the ultraviolet lamp, range from pale blue to white to yellow. Yellow is most common, but all of the concentrates that we examined contained some with both white and blue fluorescence. Occasionally, scheelite with two fluorescent colors could be seen in the same outcrop. Recently Greenwood[9] has shown that "the molybdenum content of scheelite increased from a trace in those specimens fluorescing blue to a maximum in material with yellow fluorescence."

Several tons of bismutite have been recovered from residual placers of scheelite, notably at the Bonito, and Barro Vermelho mines. It is uncertain

[9] Robert Greenwood: Effect of chemical impurities on scheelite fluorescence ECON. GEOL., vol. 38, pp. 56–64, 1943.

whether bismuth minerals were formed during the tactitization of the limestones or belong to a later pulse of mineralization. A specimen from the Barro Vermelho mine which consisted of milky quartz containing a veinlet of metallic bismuth altered on its edges to bismutite, strongly suggested that the coincidence of bismuth minerals with scheelite was a matter of superimposed mineralization rather than contemporaneousness.

Occasional crystals of molybdenite are found in some of the mines. The largest piece reported by Rolff [10] weighed about 2.5 kilos.

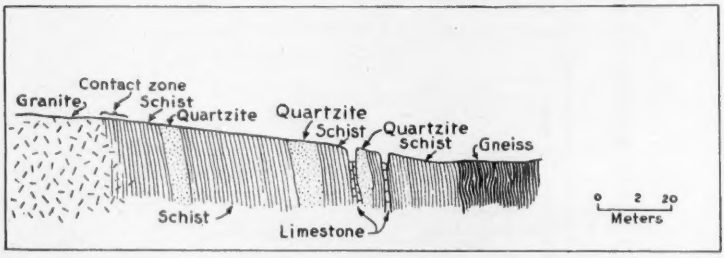

FIG. 7. Sketch section across the granite-Seridó schist contact at São Nicoláo mine.

Chalcedony replaces limestone in some mines, notably at the Bodó. Commonly it has an apple green fluorescence characteristic of uranium staining. Calcite in large crystals, with a faint pink fluorescence, is not rare. Apatite, in small (1–2 mm.) blue prisms, was seen only at the Jataí mine.

Origin.

The broad picture of the scheelite region is one of roof pendants of schist within a field of batholitic granites. This geologic environment of metasedimentary rocks intruded by granites and cut by their accompanying pegmatites and quartz veins has provided the opportunity for many contact metamorphic phenomena.

Granites at their centers of intrusion are characteristic and distinctive, but outward from these centers they merge with the schist through peripheral zones of granitized schists with the aspect of a granite gneiss. Such granitization of the schists is marked by the introduction of potash feldspar into the schist, commonly in large phenocrysts, by a coarsening of the grain size of biotite, hornblende and quartz originally present in the schist, and by the introduction of many thin lit-par-lit pegmatites. Such granitization appears to represent the first and most intense alteration of the schist.

Tungsten-bearing solutions originating in the granites appear to have moved through the schist beyond the outer limit of granitization and to have been deposited when they came in contact with calcareous beds.

The localization of the scheelite-bearing tactite in the impure limestones in preference to the crystalline marbles indicates some kind of chemical control

[10] Loc. cit., p. 357.

on which we do not, as yet, have sufficient data. The preferential location along schist contacts within calcareous beds appears to indicate that the schist or the contact itself offered freer passage to mineralizing solutions than did the calcareous beds.

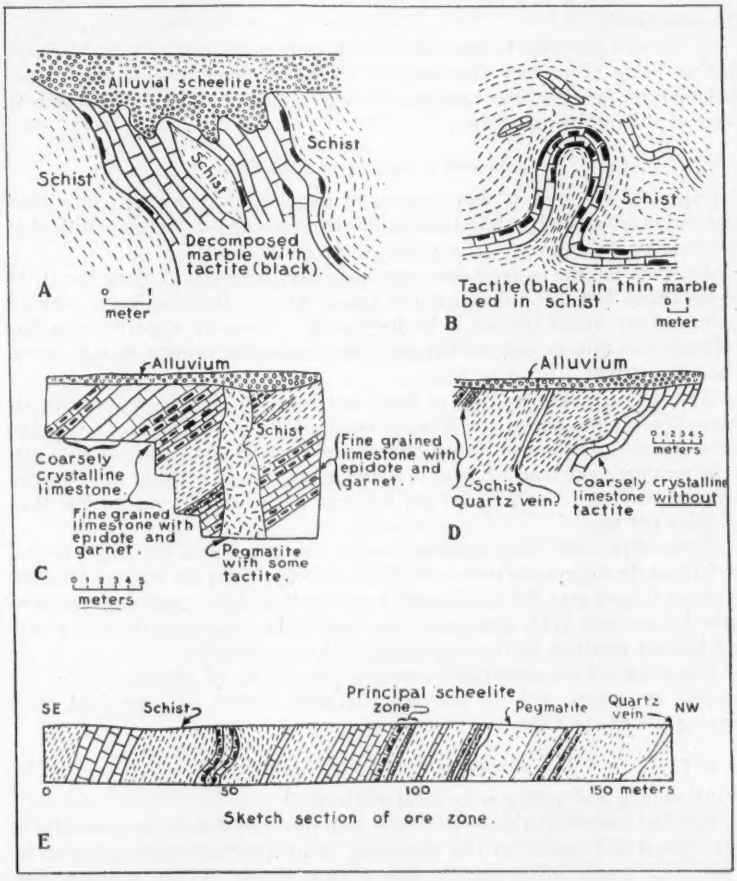

FIG. 8. Sketch sections at the Quixaba mine.

Pegmatites, consisting of muscovite (and sometimes biotite), feldspar and quartz, are present in most mines (Fig. 8), but in a region characterized by its pegmatites this is not necessarily of direct genetic significance. Indeed, it would be difficult to find a square kilometer in the scheelite region that did not have outcrops of pegmatite. Perhaps the most significant ob-

servation on the role of pegmatites in tungsten mineralization is the fact that the pegmatites at the Pitombas mine are fractured, and epidote, usually the handmaiden of scheelite, heals the fractures.

Quartz veins sometimes carry scheelite and probably are more directly related to tungsten mineralization than are either the granites themselves or the pegmatites.

It seems reasonable to conclude that these deposits can be broadly classified as being of contact metamorphic origin. Coming late in the contact metamorphic process, the tungsten-bearing solutions deposited scheelite in some of the calcareous rocks.

Size and Grade of Ore Bodies.

As all of the work to date consists of trenches and open cuts in surface material in which both residual and primary ore are mined, there are little data at hand about either the size or grade of the ore bodies.

In several of the larger mines, ore *zones* have been traced along the strike of calcareous beds for a distance of 1 km. or more. In these larger mines a pattern of ore shoots appears to be developing. Certainly, experience to date indicates that the one bed varies greatly in its scheelite content as it is traced along the strike.

The only quantitative data at hand are from Dr. Sandoval Carneiro de Almeida's exploration of the Monito mine. He found that in 20 trenches across the ore zone about 10 per cent of the lineal distance was through material yielding more than 1.8 kilos of scheelite per ton, 15 per cent was through material yielding 1.1 to 1.8 kilos per ton, and the remainder yielded less than 1.1 kilos per ton.

From ultra-violet lamp examinations of the hard ore of the larger mines, we formed the impression that most of the primary ore in the region contained less than 0.5 per cent WO_3, although some small pockets containing, perhaps, up to 1.5 per cent WO_3 were seen. In some mines, however, there is a surface blanket enriched by residual concentration of scheelite.

The grade of the concentrates ranges from 70 to 75 per cent WO_3, depending upon how well the material has been washed. In the final hand panning, losses are high.

Mining and Milling Methods.

All mining and milling is by hand methods.

Residual and alluvial material is dug with pick and shovel and generally is first washed in a "caixa" or box consisting of an open tank discharging on to a one inch screen which empties into a short flume. While washing, one workman pushes the material upward against the current with a pronged stick. Periodically, washing is stopped and the heavy material that has been collected at the head of the flume is put aside to be panned. Most of the scheelite under 2 mm. is lost in this process, and ultra-violet lamp examination of the tailings commonly shows larger pieces of scheelite.

Hard ore is drilled by hand, blasted with black powder that is made locally, and carried out of the excavation by hand, generally on a small plat-

form mounted on two sticks in the form of a short stretcher. Some of the deeper pits have simple hand-operated bucket hoists. The hard ore is then sorted and crushed by hammers or pestles. When reduced to about 5 mesh it is panned. In some mines the crushed ore is first washed in a "caixa" like that used for the residual ore.

Such hand methods are, of course, both wasteful and expensive and are possible with the low grade ores of the region only because of the low wage scale in relation to the present price of tungsten.

Recently the Bodó mine has installed a small crushing plant for hard primary ore and table and jigs are on order.

Probability of New Discovery.

At least 60 scheelite localities have been discovered in Paraíba and Rio Grande do Norte since early 1942, and new discoveries continue to be made. Present known localities are distributed throughout an area of about 15,000 square kilometers, and a similar geological environment extends over a large part of these two states whose combined area is more than 100,000 square kilometers.

As the ultra-violet lamp was not introduced into the field until July, 1943, most of these deposits were discovered without that aid. With the present production experience, more and more men in the area have learned to recognize scheelite and how to prospect for it. It is to be expected, therefore, that discoveries will continue to be made and it is very possible that better mines than those now known will be found.

MINE DESCRIPTIONS.

Explanation.

As all of the mines and prospects that were examined have been described in the Brazilian publications, some details are given here of only a few of the deposits. Figure 1 shows the distribution of the prospects that we have examined and indicates, by a heavier symbol, those that are described in the following pages.

Quixaba Mine.

This mine is about 12 km. northwest of the town of Sta. Luzia in the municipality of Sta. Luzia, State of Paraíba.

Discovered in June 1942, it had produced about 150 tons of scheelite to August 1, 1943, and was then producing at the rate of 6 tons per week, employing about 400 men. This gives 2½ kilos per man-day, the highest in the region.

A zone of marble beds in mica schists strikes northeast and dips steeply to the southeast. Trenches and open cuts (Fig. 8) have explored this zone for a distance of 2 km. along the strike, but most of the present production is from the northeast end.

The scheelite occurs in marble layers that have been replaced by epidote, garnet, and scapolite. The most productive zones are not the widest beds of

pure marble, but narrower beds of impure marble. Commonly mineralization is strongest in these thinner impure marbles on their contacts with the schist, in which they are interbedded.

Marble in the thicker beds is coarsely crystalline and ranges in color from white to gray or salmon. Commonly it contains minute crystals of pyrite and graphite, and, when freshly broken, gives an odor of hydrogen sulphide. Mineralization, *i.e.*, the introduction of epidote, garnet, quartz, wollastonite, and scapolite, generally results in a finer crystalline texture in the marble. Examination at night with an ultra-violet lamp showed that garnet, epidote, and quartz were certain guides to the scheelite. Few big crystals of scheelite are found; generally they range from 1 to 10 mm. in diameter.

Present work is (1) in the coarsely crystalline marble near the schist contacts, and (2) in thin layers of limestone inclosed in schist. Many of these thin layers are thoroughly leached and consist of residual clay residues with garnet and epidote. Alluvial production has been small.

Johnston visited this mine for the first time on June 23, 1942, two weeks after its discovery. At that time scheelite float had been traced to an outcrop of tactite. On July 27, 1943, the date of our joint visit, a pit $10 \times 8 \times 3$ meters had been sunk on that outcrop and the tactite was still yielding good scheelite.

Thin, highly folded layers are mined to the northeast of the discovery pit in a series of open cuts. As some of these cuts had reached a depth of 10 meters, the amount of sterile schist that must be removed to continue open cut mining is rapidly rising to the economic limit.

To the southwest of the discovery pit, the open cuts trace the mineralized zone for a distance of about 1½ km. However, much less work has been done here than on the northeastern end.

Granite, intrusive into the schist series, outcrops in the Serra Viola, about 3 km. distant from the mineralized belt.

As indicated in the sketches, pegmatite dikes are exposed in many of the cuts and trenches. Some of these pegmatites contain a little epidote, garnet, and scheelite, but it appears likely that these minerals were introduced into the pegmatites at the same time that they replaced the limestone, rather than that the pegmatites themselves were the mineralizing agents.

No scheelite was observed in the quartz veins at this mine.

From ultra-violet lamp examination of the various cuts, we estimated that the average tungsten content of all marble beds, wide and narrow, is of the order of 0.1 per cent WO_3, but selective mining might yield ore of 0.5 per cent WO_3 or better.

Quixeré Mine.

This mine is 15 km. east of São João do Sabugí, in the municipality of Serra Negra, Rio Grande do Norte.

The mine was opened in September, 1942, and is said to have produced about 16 tons of schleeite up to the end of July, 1943.

A bed of amphibolite, 1½ to 2 meters wide, containing a few relics of coarsely crystalline marble, has been strongly epidotized and silicified. The

bed dips steeply and conforms with walls of granitized schist that might almost be called gneiss. Scheelite appears to be most abundant in or near the marble relics that have not been altered to amphibolite. Where the amphibolite has been strongly epidotized, the scheelite appears most abundant at the schist contact. Garnet is relatively rare and is confined to quartz veins that cut the amphibolite bed. Small pegmatite dikes, 10 to 40 cm. wide, are also present.

Several open cuts and trenches have exposed the amphibolite bed for a strike length of about 500 meters. The average scheelite content appears to be less than 0.5 per cent.

Bonito Mine.

Bonito mine is on the west side of the Rio Piranhas, about 27 km. north of São Miguel da Jucurutú, in the municipality of that name, Rio Grande do Norte. It is about 2 km. from the river on the east slope of Serra do João do Valle.

A series of thin beds of epidotized amphibolite striking northward and dipping steeply to the west can be traced for about 1,400 meters (Fig. 9).

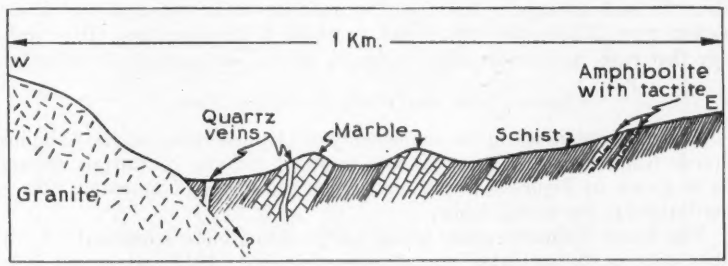

FIG. 9. Sketch section at the Bonito mine.

The amphibolite is interbedded with sandy schists. West of the amphibolite is a series of marble lenses whose outcrops rise above the enclosing schist, and still farther west is a pink fine-grained granite. The schist-granite contact is concealed, but there appears to be no conspicuous contact metamorphism of either limestone or schist and, for that reason, it is assumed that the contact is a fault.

The marble is medium-grained, granular, with some graphite specks, and it yields a strong odor of hydrogen sulphide when freshly broken.

The amphibolite zone is 2 to 10 meters wide. It is marked by strong outcrops of green epidote rock cut by a network of quartz veins.

Scheelite occurs in the quartz veins and in the adjacent walls of epidotized amphibolite. Crystals are usually small but a few up to 5 cm. in diameter were observed. In a few outcrops the scheelite crystals were arranged in definite bands in the epidotized amphibolite suggesting some type of selective replacement of earlier textures.

It appears fairly clear that in some cases, at least, the quartz veins intro-

duced the scheelite, but it is uncertain whether the scheelite-bearing quartz is confined to the amphibolite zone. To the west, near the granite contact, there are several very large quartz veins cutting both marble and schist, but these appear to be barren.

Much of the scheelite recovered to date is in residual material.

Other minerals observed were bismutite, pyrite, and molybdenite. Some garnet is found in the panned scheelite concentrate but, unlike most other scheelite deposits in northeastern Brazil, garnet is not a common mineral at Bonito. Some chalcedony with green fluorescence and calcite with pink fluorescence were also observed.

Bismutite, in angular fragments, is obtained in panning scheelite. A few specimens of bismutite veinlets in quartz were observed. Probably the bismutite is a weathering product of veinlets of metallic bismuth.

Prospecting this deposit is under the direction of Dr. Sandoval Carneiro de Almeida, who has laid out a series of trenches to cross-cut the amphibolite zone. Of the trenching so far done about 10 per cent of the linear footage gave material yielding more than 1.8 kilos of scheelite per ton and 15 per cent gave material yielding between 1.1 and 1.8 kilos of scheelite per ton. Thus the bulk average is less than 0.1 per cent WO_3. One of the richest pockets gave 22 kilos per cubic meter, or about 10 kilos per ton. It is probably that here, as in most other tungsten mines, mining must be selective.

Barra Verde and Barro Vermelho Mines.

These two mines are in the municipality of Currais Novos, on the Campina Grande-Natal highway, about 12 km. south of the city of Currais Novos. As is shown in Figure 10, both are on the same lens of limestone that is interbedded in the Seridó schist.

The Barro Vermelho mine, which has produced more scheelite than any other mine in the northeast, was discovered in early 1943 and, in late July of that year, about 3,000 men were working there. In early 1944, the mine was closed to await more favorable marketing conditions.

The Barra Verde mine, on the southern extension of the limestone bed, was discovered a short time later and has been worked continuously since its discovery.

A bed of white coarsely crystalline marble striking north-south can be traced for about 3½ km. At its northern end where it dips about 50° west it is 150 meters wide; toward the southern end of the Barro Vermelho mine the dip flattens to 40° and the width of the limestone outcrop is about 300 meters. In the Barra Verde mine, the dip steepens southward and, at the southern end of the mine, the dip is 85° where the width of the outcrop is about 25 meters. Although the outcrop width reflects the dip, the bed also narrows to the south. Its true form probably is lenticular.

Mineralization consists of epidote, garnet, vesuvianite, some hornblende, and scheelite. As is shown on the map, prospect pits follow both contacts. Those prospect pits away from the contact are mainly in residual alluvial material.

About five kilometers to the southwest is a large intrusion of gray granite centering in the site of the Acarí dam. This granite extends to within about

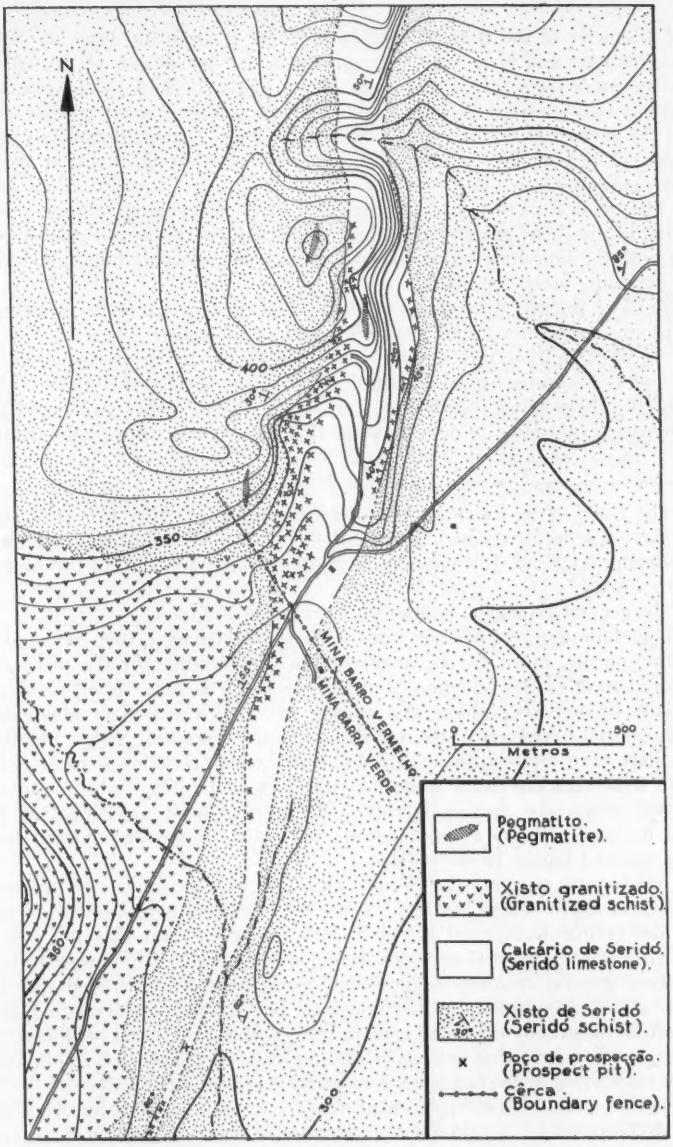

FIG. 10. Sketch map of the Barra Verde and the Barro Vermelho mines showing the location of the prospect pits in a marble layer interbedded in the Seridó schist.

one kilometer of the Barra Verde mine where it gradually loses its distinctive character and gives way to granitized schist, which extends to within a few meters of the southern end of the Barro Vermelho mine. The granitized schist is characterized by phenocrysts of fresh feldspar, many granite dikes, and the general aspect of a gneiss, which, however, is transitional into biotite schist. The boundary of granitizations, as shown on the map, at best, is only approximate.

The general picture strongly suggests that mineralizing solutions, originating in the Acarí granite, moved through the schist until they came in contact with the limestone bed where the contact metamorphic minerals, including scheelite, were deposited.

A more intense, or perhaps earlier, permeation of the schist resulted in its progressive granitization from the center of intrusion.

All work in these mines is by hand methods of mining and panning, and most of the scheelite so far obtained is from soft surface material in which there has been some residual concentration. Both mines are worthy of systematic exploration to determine the distribution and tenor of the primary ore.

Bodó Mine.

The Bodó mine, which was discovered in August, 1943, produced about 400 tons of scheelite through March, 1944. The mine is in the Municipality of Santana do Mato, Rio Grande do Norte, about 18 km. from the town of Cerro Corá.

The general geological relations are shown in Figure 11.

Thin limestones interbedded in the Seridó schist have been replaced by epidote, garnet, much quartz, and scheelite. Weathering of the tactite has removed most of the remaining limestone and left a soft, clayey residue of partially decomposed epidote and garnet, with much secondary chalcedony. This material is panned to recover the contained scheelite. Other limestone beds have been replaced principally by quartz which contains some scheelite. All of these beds dip to the south. At the foot of the hill, fresh limestone is exposed which also carries scheelite. It appears most probable that this fresh limestone bed is a continuation, down dip, of the decomposed limestone exposed higher in the hillside.

Granite sills injecting the Seridó schist are exposed in two of the open cuts on the north side of the hill. From the restricted exposures, it appears that the granite is injected lit-par-lit into the schist, and that the granite contact dips southward closely underlying the mineralized limestone beds.

These general relations suggest that the granite was intruded into the Seridó schist close to several thin limestone beds and that mineralizing solutions from the granite deposited epidote, garnet, and scheelite in the limestone. Subsequently, weathering has leached the unreplaced limestone near the crest of the hill leaving a residual blanket of partly decomposed silicates.

The beds which were replaced principally by quartz, however, have not been decomposed by weathering. It is planned to crush this hard material and to recover the contained scheelite by tabling. An inclined plane consisting of two tracks for lowering in balance has been constructed, and a crushing plant is located at the foot of the hill.

Cafuca Mine.

The Cafuca mine is 54 km. northwest of Cerro Corá in the Municipality of Santana do Mato, Rio Grande do Norte. It was discovered in July, 1943, and is said to have produced over 200 tons of concentrates in the first nine months of its operation.

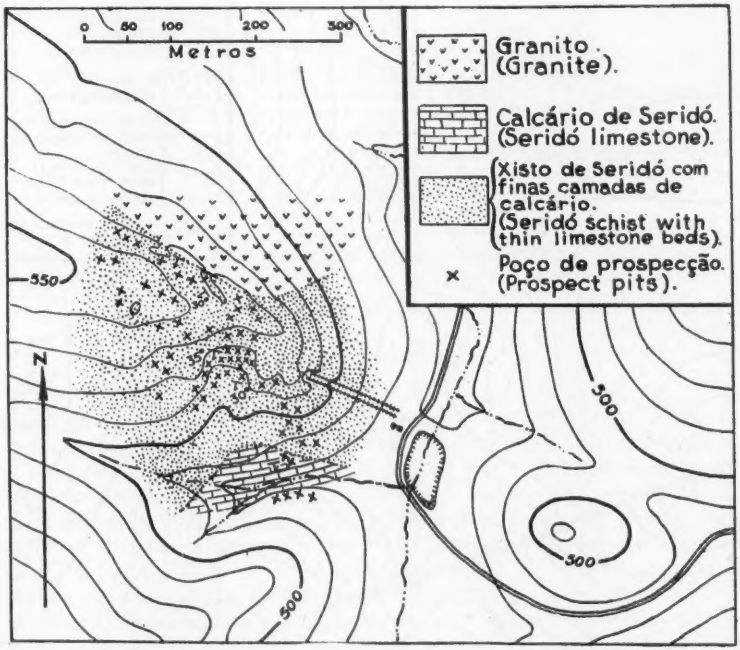

FIG. 11. Sketch map of the Bodó mine.

The general geological relations are shown in Figure 12.

Seridó schist, with thin interbedded limestone, strikes northward. On the west of the mine, the limestone dips to the west, and on the east side there are several small folds which dip both east and west. The limestone layers, which range in thickness from a few centimeters to more than 5 meters, have been altered to an epidote and quartz tactite. Additional contact metamorphic minerals present in lesser amounts are vesuvianite and wollastonite. Scheelite occurs with both epidote and quartz. The largest single crystal of scheelite found during the first nine months of operation weighed about 3 kilograms.

A gray medium grained granite is exposed in the hill in the northeast corner of the map. This granite merges with the schist through a granitized zone in which phenocrysts of fresh pink feldspar up to 5 cm. in diameter have

been introduced into the schist. Thus the contact, as shown on the map, is only approximate and marks the limit of granitization rather than of granite.

A very conspicuous pegmatite dike over one km. in length terminates in the eastern workings. This pegmatite, however, appears to bear no relation to the process of tungsten mineralization.

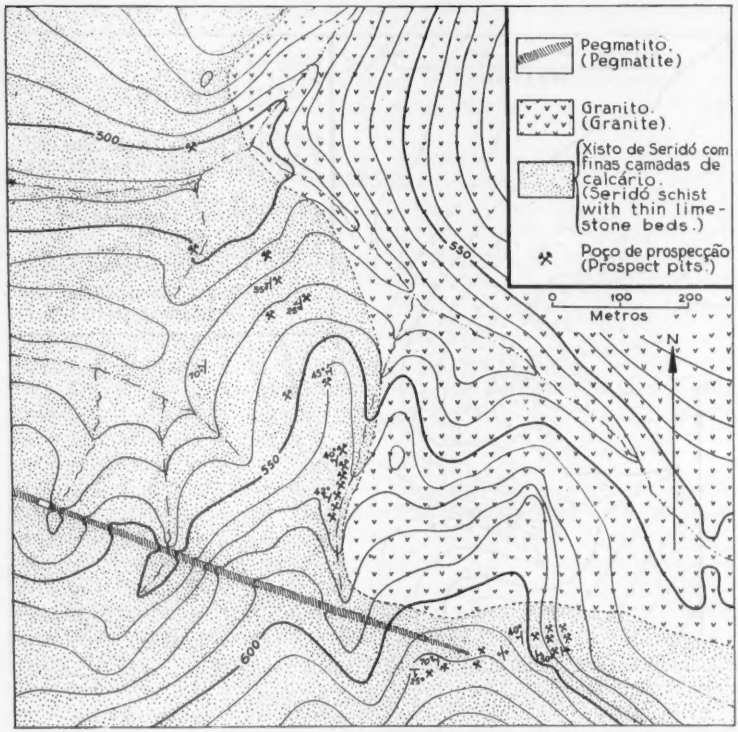

FIG. 12. Sketch map of the Cafuca mine showing location of the prospect pits along the granite-schist contact.

At the Cafuca mine, as at the others previously described, mineralization is confined to limestone beds near a granite intrusive. Here, too, the mineralizing solutions moved through the schist and deposited the contact metamorphic silicates and scheelite in limestone at the schist-limestone contacts.

Although much of the initial production came from residually enriched surface material, this mine appears to be worthy of exploration to determine the extent and value of the primary ore.

RIO DE JANEIRO, BRAZIL,
Aug. 9, 1944.

FISSURING IN SANDSTONES.

E. SHERBON HILLS AND D. E. THOMAS.

ABSTRACT.

The structure known as "fissuring" is widely developed in sandstones interbedded with slates in the closely folded marine Ordovician rocks of the goldfields of central Victoria, Australia. Fissures are here described, and interpreted as flow layers analogous to those that form in plastically deformed metals. In fissured sandstones, two complementary sets of microscopical shearing planes are present, with the bisectrix of the acute dihedral angle between them normal to the bedding. Fissures form in both of these shearing directions, and also in the plane of flattening of the rock.

Closely spaced fissures in sandstones and puckered arenaceous laminae in slates are used in field work to indicate center country (fold axes) where dip readings are difficult to obtain, and it is also suggested that basal deformations of sandstones may be used as a guide to facings in disturbed strata.

INTRODUCTION.

In the closely folded marine Ordovician rocks of central Victoria, a variety of minor structures such as the fissuring of sandstones originally described by Dunn,[1] puckering of laminated sandstones in slates, and basal deformations of sandstones such as have also been studied in the Silurian rocks of the Melbourne district[2] are admirably preserved and exposed. Most of our observations on these structures were made in the Castlemaine, Bendigo, and Chewton districts while one of us (D.E.T.) was surveying the Chewton goldfield, but similar features are known to occur in the Ordovician rocks of other areas, *e.g.*, the Ballarat and Daylesford goldfields. It is possible that the fissuring is the same structure as the coarse or rough cleavage often referred to in the literature as existing in sandstones interbedded with slates, but it has many unusual properties, and the available descriptions of cleavage in sandstones do not permit a decision on this point.

In all parts of Victoria, the Ordovician rocks have been closely folded, and so far as is known all the folds are of a similar type. At Bendigo, anticlines have been followed in depth for over 4,500 feet without significant change of form. The axial lines, which have been mapped in detail at Bendigo, Castlemaine, and Chewton, are closely spaced, as many as five or six anticlines occurring in a mile. All the strata show an apparent thickening at the fold axes and thinning on the limbs, slates increasing in apparent thickness on the average up to three times the width on the limbs. Cleavage

[1] Reports on the Bendigo Gold-Field (Nos. I and II). Special Repts., Dept. Mines, Vict., 1896.

[2] Hills, E. S.: The Silurian rocks of the Studley Park district. Proc. Roy. Soc. Vict. 53 (1): 167–191, 1941.

is developed in the argillaceous strata, and fissuring in many of the sandstones, but otherwise the rocks are unmetamorphosed in the districts studied. The auriferous quartz reefs of the goldfields are of post-cleavage date, so that for the purposes of the present account, no processes other than those connected with deposition, lithification, and folding need be considered.

The rocks consist of alternating grits, sandstones, argillaceous sandstones, arenaceous mudstones, fine-grained mudstones, and shales, the argillaceous types being now for the most part slates. In the sandstones, apart from one record of fragments of shells, there are no fossils; in the shales, graptolites,

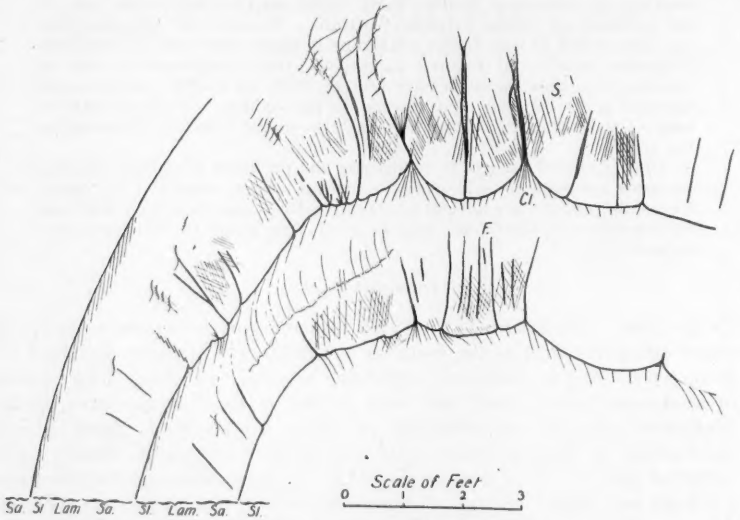

FIG. 1. Detail of east limb and axis of Napoleon Anticline at surface, Golden Square, Bendigo. Sl., slate; Sa., sandstone; Lam., laminated sandstone; Cl., cleavage in slate; F., fissures; S., complementary shearing planes.

phyllocarids, and, rarely, thin-shelled chitinous brachiopods occur. At no locality do either the arenaceous or the argillaceous strata markedly predominate. The beds are generally thin, maximum thicknesses being about 20–30 feet for the sandstones, and 50–60 feet for the mudstones. In the thicker mudstone belts, only a small part is as a rule graptolitic. Graded bedding and small-scale current bedding are common.

In interpreting minor structures in the Castlemaine-Bendigo district, four distinct and frequently occurring lithological types have to be considered. These are (1) quartzose sandstones and argillaceous sandstones; (2) laminated sandstones; (3) argillaceous slate with interbedded sandstone laminae or layers; (4) argillaceous slates. In many places, this series together constitutes a definite unit of sedimentation, with sandstone at the base, grading through the laminated rocks to slate. Where such a gradation occurs, it

permits a correlation of the different structures in each rock type, based on the nature of the movements that are so clearly revealed by the laminated rocks. An example is afforded by the Napoleon anticline at Golden Square, Bendigo (Fig. 1), in which exposure we see two complete graded beds. The lithological relationships in this example, though common, are not universal, and with different types of strata variants of the structures illustrated are found.

STRUCTURAL DETAIL.

1. *Fissuring.* Fisuring is typically developed in massive sandstones, especially in argillaceous sandstones, and was originally described by Dunn [3] as follows: "The rock literally had been sliced through along the lines so strongly marked in the plate. The fissures along these lines are filled with a fine material, probably resulting from the grinding together of the two sides of the fissures; it is frequently micaceous." Although fissures as exposed in mines may in places be open cracks, in surface exposures they are usually closed, but may weather into deep grooves, or stand out as ridges. It seems probable that where they are open in mines, they have generally become so as a result of blasting, but, nevertheless, the term "fissuring" so aptly fits their normal appearance in the field that it is proposed to retain it.

Fissures, as considered in this paper, are zones, varying in width up to about an inch, in which the rock has been strongly sheared and mashed. They make a high angle with the bedding, generally about 90° near fold axes and also in places on the limbs, but in some places they lie at 50°–60° with the bedding on fold limbs, dipping towards the axis in anticlines and away from it in synclines. Thus, considered broadly, fissures are radially arranged in folds, like the ribs of a fan, but this simple relationship, such as is shown in Figures 1 and 6, is often complicated by the presence of short fissures crossing the main set at an acute angle, and by branching and linking of fissures. These effects are seen both in cross section and along the strike, and in places they are so marked that the presence of two distinct sets of intersecting fissures may be definitely recognized. It is, however, very probable that in some instances the two sets developed at different times, the later in relation to structures such as minor steeply-pitching flexures on the limbs of larger folds. It is equally probable that in other examples the two sets are congenetic, if not contemporaneous.

In the general direction of the strike, fissures may be fairly straight and parallel, or pronouncedly arcuate, as shown in Figure 2.

Where fissures cross stratification planes, these are always displaced. On fold limbs the displacements are generally shears, with movements ranging up to about an inch, but generally less (Figs. 2, 3a). In the vicinity of fold axes, however (and rarely on fold limbs), the bedding planes usually bulge between the fissures, the "drag" on both sides being in the same sense, so that one cannot regard the fissures as simple shear planes (Figs. 1, 3b). This gives the appearance of the rock having been "sliced through" along

[3] Op. cit.

the fissures as by a knife in cutting putty, and suggests some type of localized mass movement along them. In spite of this apparent difference between the movements on certain fissures, there is no noticeable difference in the nature of the planes themselves, and no discontinuity in the general pattern of fissuring between the various parts of a fold.

Where sandstones differing slightly in texture are superimposed, the spacing of the fissures may be different in each stratum, but normally there is no abrupt change in their attitude relative to the bedding in the different strata. In graded beds, however, there is a gradual change in the attitude of the structures as the bed becomes more argillaceous. The true fissures

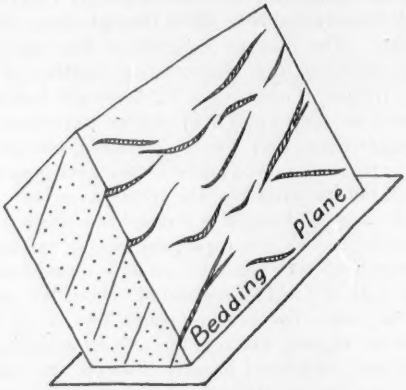

FIG. 2. Sketch of exposure of sandstone showing curvature of fissures on bedding plane, and normal slip on fissures, Castlemaine.

in massive sandstone near the base of the bed pass upwards into zones of shearing in the overlying laminated rocks, in which displacements of an inch or more are shown by the arenaceous laminae (Fig. 1). Similar shear zones occur in laminated sandstones interbedded with massive slates (Fig. 3c) in which examples true fissures are absent since massive sandstones are not present. Although it is clear that shear zones in laminated sandstones have much in common with true fissures in massive sandstones and must be regarded as genetically related to them, they differ in that the disturbance is generally distributed over a greater breadth in the laminated rocks, and the mashing is consequently less intense, so that the appearance of the rock having been sliced or sheared through along a well-defined narrow zone is not presented. We propose, therefore, to use the term "fissuring" for the typical structures as developed in sandstones, and to refer to the analogous structures in laminated rocks as "shear zones."

As with fissuring, the displacements in these shear zones are not always simple shears. A succession of simple shears in the same sense in adjacent zones is commonly found in fold limbs, but in the vicinity of fold axes the

displacements are variable in sense not only from zone to zone but also in different parts of the same zone (Fig. 3d). Intensely complicated deformations, known as "puckering" (Fig. 4), occur in places near the axes of folds and are a useful indication of the proximity of axes in slate belts where the bedding is difficult to recognize or disturbances due to hill-creep make dip-readings uncertain.

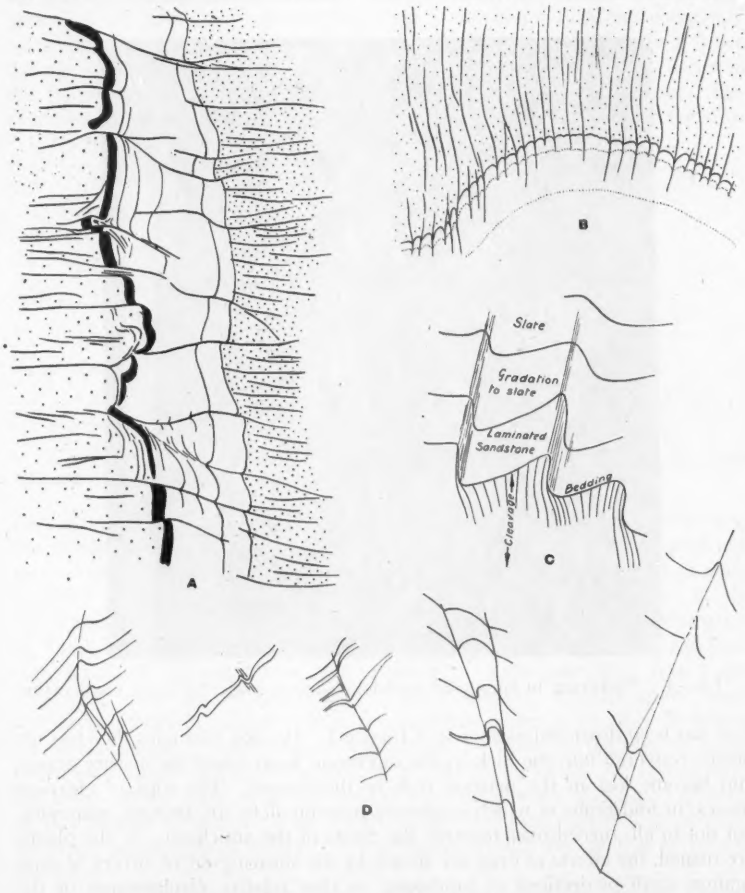

FIG. 3. A. Detail of fissured rocks on fold limb. × ⅙. B. Fissured sandstone (stippled) at anticlinal axis, No. 4 Level, Golden Pyke Mine, Bendigo (after Dunn). Showing cusps in sandstone base at fissures. C. Detail of shear zones in laminated sandstones interbedded with slates. × ⅓. D. Various types of deformation on shear zones in laminated sandstones near fold axis. × ⅙.

2. *Relation to Cleavage.* In graded beds, the argillaceous tops develop slaty cleavage, which passes down on a smooth curve into the shear zones of the laminated layers and thence to the fissures in the massive sandstone beneath. The curve terminates abruptly at the base of the sandstone where this rests on slate, and there is no visible continuity of structure from the underlying slate into the fissured sandstone except along certain especially well-defined fissures that reach the base of the sandstone, and along which the

FIG. 4. Puckering in laminated sandstone-slate at anticlinal axis, Castlemaine.

base has been disturbed as shown in Figure 1. In such examples the cleavage planes converge into the nick in the sandstone from which the fissure arises, and become lost in the mashed rock in the fissure. The tops of cleavage planes, in fold limbs in which sandstone rests on slate, are in some examples, but not in all, turned over towards the crests of the anticlines. If the planes are turned, the effects of drag are shown by the shearing-off of slivers of slate against small projections of sandstone, so that relative displacement of the beds along such slate-sandstone junctions may be assumed.

3. *Major Fissures.* It is mentioned above, and may be seen in Figures 1 and 6, that certain fissures intersect the base of the sandstone in which they occur, while others do not. In some cases, those that do not intersect the

base arise at a more or less well-defined level which probably marks some lithological change, very probably from less argillaceous material below to more argillaceous above. Fissures that pass through this lower layer and intersect the base will be termed "major fissures," and such invariably arise at points where the base of the sandstone exhibits some type of cuspate involution. At first sight, the intimate connection between fissuring and cleavage and these cuspate involutions of argillaceous and arenaceous rocks suggest that the latter are tectonic, but there is no doubt that one commonly occurring type (Fig. 5) originated before the cleavage and fissuring, since exactly similar structures, termed "basal sandstone deformations," occur in the folded but non-cleaved Silurian rocks of the Melbourne district. Detailed examination of these [4] indicates that they were formed during the soft-

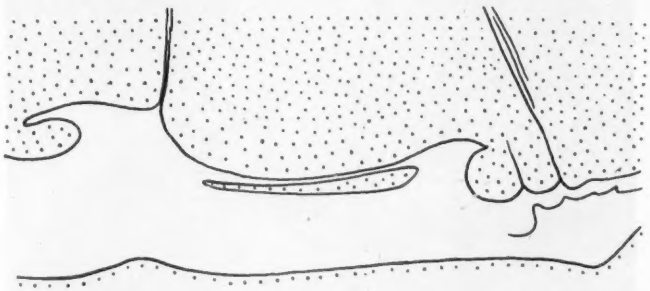

FIG. 5. Basal sandstone deformations, with fissures arising from nicks in the sandstone base. Slate blank, sandstone stippled. × ¼.

rock stage, probably as a result of effects connected with the compaction of the sediments. Closely analogous structures are also found in the mud and sand slurries of old mine slump-dumps, and similar forms are found in some slumped sediments.[5] We do not, however, regard these structures in the rocks under discussion as being due to submarine slumping. The origination of major fissures from pre-tectonic mudstone involutions or injections into sandstone indicates that the presence of such structures was a determining factor in the localization of these fissures. On the other hand, the development of cuspate forms in sandstone bases is in some instances a tectonic feature. In the Napoleon Anticline, for instance, the regular, large, downward bulges of the sandstones, with intervening cusps, are restricted to the axial region of the fold, and similar relationships are also found in folds at Castlemaine (Fig. 6). Such features, therefore, are regarded as tectonic, and may perhaps be an effect of compression beneath the neutral surface in the folds.

As with the pre-tectonic basal sandstone deformations, major fissures arise at these cusps, the cleavages converge into them, and in some instances

[4] Hills: op. cit.

[5] Hadding, A.: On sub-aqueous slides. Medd. Lunds. Geol. Min. Inst., No. 47: 377–393. 1931.

there appears to be a definite injection of slate into the sandstone from the points of the cusps. Rarely, similar bulges and cusps are found at synclinal axes.

Our observations over large areas of Silurian and Ordovician rocks in central Victoria indicate that pre-tectonic basal sandstone deformations are a reliable guide to the facing in disturbed strata. Such deformations are characteristically restricted to the lower surfaces of sandstones, this being a corollary of the hypothesis presented to explain their formation.[6] In thin sandstones, the disruptive effects of the injection of mud from below may be

FIG. 6. Fissuring of sandstone in drag fold, Castlemaine. (Significant detail emphasized in black.)

transmitted through the bed, thus making the interpretation of facing difficult, but with thick sandstones the intricate lobation and injection of the base is not continued to the upper layers, which are undisturbed.

4. *Shear Phenomena in Fissuring.* From the above description it will be realized that structures classified in the field as fissures are all alike in that they are zones, of variable width, along which mass displacements of the rock have occurred. On fold limbs these displacements are generally demonstrably shearing movements, but, especially near fold axes and in major fissures arising from nicks in the sandstone bases, simple shearing is not definitely indicated, but rather a localized plastic flow along the fissures, so that the "drag" on both sides is in the same sense. Mechanical disruption of the component grains of the sandstones is characteristic of all fissures, but the rocks cleave between as well as along the fissures, and shearing of the quartz

[6] Hills: op. cit.

grains in the material between the fissures is seen under the microscope. Plastic flow was, therefore, not confined to the fissures but permeated the whole rock.

In thin sections, while a general shearing of the quartz grains is obvious, the eye does not readily synthesize this into a pattern of one or more shearing planes. Close examination of natural exposures, however, reveals that in fissured sandstones near fold axes a pattern of two sets of planes intersecting at an acute angle varying about 30°–45°, and marked by a very fine lineation of weathered surfaces, is present (Fig. 1). In general, these two sets are about equally developed, but in places one is dominant. As the beds curve in folds, the attitude of the planes changes in sympathy, in such a way that the bisectrix of the acute angle between them remains normal to the stratification.

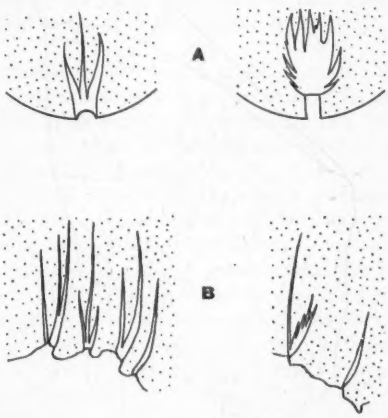

FIG. 7. A. Flow layers arising from grooves in metal rods (after Nadai). B. Major fissures arising from nicks in sandstone, Bendigo.

Examination of thin sections shows that these two lineations correspond to more or less equally developed sets of shearing planes which are regarded as complementary and congenetic.

On the limbs of the folds, the fissures tend to assume parallelism with that set of shearing planes which encloses, with an underlying bedding plane, an acute angle pointing downwards. Very rarely on the limbs, a fissure is parallel to the other set of shear planes. Some irregular fissures also occur and may be accounted for by original non-homogeneities in the rock, or by local stresses set up during deformation. At and near fold axes, on the other hand, fissures form also in the plane of the bisectrix of the acute dihedral angle between the microscopical shear planes, in what is regarded as the plane of flattening in the rock. A radial arrangement of fissures, which is best exhibited in very closely fissured rocks, is thus produced at the axes as shown in Figure 6, and also in the excellent illustrations given by Dunn. The

formation of fissures in the plane of flattening is taken to indicate that in this plane certain zones of the rock were more mobile than the intervening material, and yielded by plastic flow, so producing the effect of matching drags on either side of the fissures.

It is clear that all fissures are zones of especially strong plastic deformation, and they are regarded as analogous to the flow layers that form in deformed polycrystalline metal test pieces. Major fissures are especially significant from this point of view. Nadai [7] figures numerous examples of the concentration of flow layers at points where some irregularity in a test piece, such as a hole or groove, causes stress-concentration. The similarity

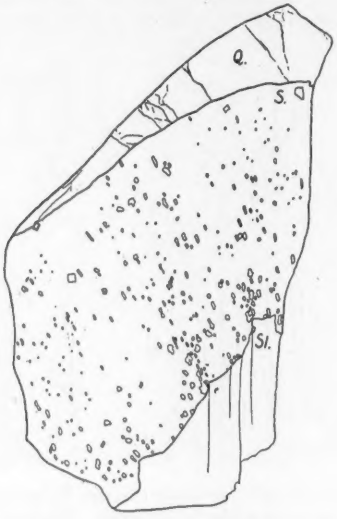

FIG. 8. Portion of saddle-reef, Bendigo. × ⅔. Q., quartz; S., sandstone with oriented arsenopyrites and some pyrites; Sl., slate.

between the origination of flow layers from grooves in metals subjected to pure shear, and of major fissures from nicks in sandstone bases, is particularly striking (cf. Fig. 7a, b). The arrangement suggests axes of extension and shortening that agree with the strain axes inferred from the attitude of the complementary shearing planes, assuming as is most likely that the obtuse dihedral angle between these contains the least axis of strain.

5. *Relation to Mineralization.* A specimen from Bendigo (Fig. 8), consisting of half a small saddle reef, shows that the planes of movement formed during plastic flow in sandstones are important in controlling the orientation of elongated crystals of arsenopyrite in a sandstone in which fissures are not present. The marked concentration of orientated sulphide crystals in the

[7] Plasticity. McGraw-Hill, New York, 1931. Chap. 21.

sandstone where nicks occur in its base is also to be compared with the situation and shape of major fissures that occur in other rocks at such points. These significant relationships suggest the desirability of further investigations of the connection between mineralization and intimate cleavage structures in the goldfields.

ORIGIN OF FISSURING.

Construction of strain ellipsoids in a sandstone stratum, on a basis of the attitude of fissuring and microscopical shearing planes, leads to the result that the major axis of strain is everywhere normal to the bedding, the least axis parallel to it, and the intermediate axis very probably parallel to the pitch. This arrangement is indicative of the influence of compression parallel to the bedding on the concave surfaces of neutral-surface folds, with which the tectonic bulges at fold axes, as in the Napoleon Anticline, also appear to be connected.

Fissures are regarded as flow layers in which plastic flow was especially strong, and which emphasize the internal movement in the deformed sandstones. Thus, on fold limbs there is a general tendency for the displacements on fissures to be "normal" slips, which have the effect of increasing the dip, and which are preferentially developed on one of the sets of shearing directions. At the axes, on the other hand, the effects of compression on the concave surfaces of folds are stronger and the fissures develop preferentially in the plane of flattening of the rock. The amount of plastic deformation required of the sandstones is, in general, greatest near the fold axes, so that a large number of fissures would be expected to develop there.

Finally, there appears to be a certain general similarity between fissures and the structures in limestones recently described by Price and Lucke [8] and regarded by them as primary in origin. A closer comparison of the two structures would be of interest.

[8] Price, P. H., and Lucke, J. B.: Primary limestone structures of West Virginia. Amer. Jour. Sci. 240: 601–616, 1942.

REVIEWS*

Tectonic Map of the United States. Committee on Tectonics, Division of Geology and Geography, National Research Council. CHESTER R. LONGWELL, chairman. 7 colors; 2 sheets; scale, 1:2,500,000; overall size, 80″ × 50″. Am. Assoc. of Petroleum Geologists, Tulsa, 1944. Price, $2.00 rolled, $1.75 folded.

The following paragraphs, quoted from an account of the map written by Chester R. Longwell and published in December, 1944, in the Bulletin of the American Association of Petroleum Geologists, explain the chief features of the map and the principles followed in its construction.

The following paragraphs, quoted from an account of the map written by Chester R. Longwell and published in December, 1944, in the Bulletin of the American Association of Petroleum Geologists, explain the chief features of the map and the principles followed in its construction.

"The map in its present form represents evolution and adjustment, during several years, of ideas contributed by committee members and other friends of the project. Inevitably the adjustment involved numerous compromises, and probably the final result will not be completely satisfactory to any individual. Users of the map should be given, as fully as possible, advantage of the study and discussions which have led to decisions by the committee that are reflected in construction of the map.

"Although the concept of maps specially constructed to represent tectonic features is by no means new, the committee found no precedent in any published map of this kind showing to a fairly large scale an area as large and structurally diversified as the United States. What can and what should be represented on a structural map of this country drawn to a scale of 40 miles to the inch? What are the most effective techniques for delineating the various kinds of structural features? There are no standard specifications for tectonic maps. Of such maps now in print, many purposely omit all but the major structural units, with the intent of focusing attention on orogenic belts and their outstanding characteristics. Other maps single out special groups of structural features, whether large or small, which show relationships of particular interest to the authors. Some maps represent structural features according to kind and without regard to geologic date of origin; others make differences in age the matter of chief importance, or attempt to combine the historical and strictly physical aspects of deformation. Existing tectonic maps differ widely also in the use of structure-symbols and other devices for representing particular features and concepts. Many maps that are labeled 'structural' or 'tectonic' are little more than modified geologic maps; and of course a good representation of lithologic units, combined with plentiful and clear structure-symbols, is an excellent and familiar means of conveying some concepts of geologic structure. However, patterns to represent rock formations often

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

obscure or even exclude patterns to show critical structural features, and some combinations aimed at serving both purposes are unsatisfactory from both points of view.

"Confronted with a wide range of choice in the matter of technical method, the committee faced also the more fundamental problem of the purpose the map should try to serve, which would in large part determine its content. Would the greatest need be served by an objective representation of known structural features, or by an 'interpretative' diagram that would include much factual material but would go much further in portraying inferred relationships? Undoubtedly the latter type of map would be more attractive in appearance, since it could be made 'pictorial,' could give an impression of completeness even where knowledge is lacking or meager, and could convey direct suggestions of interpretations that are stimulating even if somewhat questionable. Members of the committee agreed unanimously on the objective type of map, to portray as accurately as possible the known facts about structural features, in as much detail as the chosen scale would permit. This decision does not indicate an opinion that maps of the other type are not valuable. Geologic science is advanced by intelligent speculation, and provocative interpretation of structural relations often serves to stimulate efforts that result in discovery of important facts. However, maps that rely to any extent on imagination are produced more successfully by individual authors than by large committees in which viewpoints differ and often conflict. Moreover, legitimate interpretations must have a factual basis, and no earlier map of the United States with comparable scale pretends to assemble the established structural information.

"Some disappointment has already been expressed because adherence to the principle of showing only known structural features has not permitted representation of 'probable faults' in the Basin-and-Range region of Nevada and adjoining states, where a number of the ranges are known to be fault blocks. However, some of us who have made field studies in that region know that existing maps showing assumed faults at borders of ranges are untrustworthy and in some cases give serious misinformation. Complexity of the structure in much of the region is suggested by the structural pattern in the few parts of it that have been mapped with care. It was decided to bring out the general 'grain' of the region by distinguishing alluviated basins from the bedrock of adjoining ranges, and to print 'structure unnkown' across the larger unmapped areas. Such an honest indication of outstanding gaps in knowledge may, by focusing attention on virgin territory that holds the possibility of large rewards for geologic field study, incite efforts that will hasten completion of our geologic mapping program.

"*Representation of bedrock.*—The committee agreed that in general a tectonic map should portray structural features without regard to kind and age of bedrock involved. A few conspicuous exceptions to this rule appear on the map.

"(1) Large outcrops of pre-Cambrian rocks indicate structural 'highs,' and a distinctive color-pattern for these areas helps users of the map by 'spotlighting' some of the most significant structural units. Subdivision of the pre-Cambrian bedrock according to general lithology is a further attempt to portray structural relations, though only the larger outlines are known and these imperfectly. Trends of schistosity are indicated so far as information is available; igneous bodies forming massive units are shown by a distinctive pattern; late pre-Cambrian stratified rocks bear marks of deformation essentially like those in younger stratified formations.

"(2) Several metamorphic 'complexes,' containing rocks of diverse types and partly of unknown age, form structural units that merit special recognition. Thus the strongly deformed rocks of New England and the Appalachian Piedmont share the characteristic of complicated and as yet incompletely unravelled orogenic struc-

ture. Somewhat similar units in western United States consist largely of metamorphosed Paleozoic and Mesozoic rocks.

"(3) Certain sedimentary deposits, such as the Triassic strata of the East and late Cenozoic basin-fill in some western States, mark areas that are structurally negative. Conspicuous color-patterns 'spotlight' these areas, just as the pre-Cambrian symbol focuses attention on structural 'highs.'

"(4) Prominent unconformities and structural basins are brought into relief by representing outcropping basal contacts of several sedimentary systems and series. Horizons marked on the map for this purpose are the base of the Pennsylvanian in the eastern part of the country, the base of the Cretaceous at the inner edge of the Coastal Plain and farther northwest, and two Tertiary horizons widely distributed.

"(5) Batholiths, stocks, and related igneous bodies are structural units in their own right, and they generally are closely related to belts of orogeny. Moreover, identification of these masses is required for a clear understanding of the map, since folds and faults in sedimentary rocks commonly end abruptly at the margins of an intrusive body. Dikes that occur in groups or swarms probably have tectonic significance, even if no larger related igneous bodies are visible.

"(6) Lavas covering large areas in several western States effectively conceal structural features in the older bedrock. Disappearance of tectonic features at the margins of lava fields would be misleading if the lava-covered areas were not indicated. Furthermore, volcanism in itself has tectonic significance. The map does not pretend to represent all volcanic areas, however; only the most important and extensive areas of Tertiary and Quaternary volcanic rocks are indicated. Moreover no close consistency is observed in the geologic age of these rocks that are shown in different parts of the map. In the Columbia Plateau and adjacent provinces the Columbia River lavas are the oldest that are represented; whereas some older volcanic rocks are shown elsewhere, as in New Mexico, Colorado, and Texas. Tectonic significance has been the chief guide in selecting certain units of volcanic rocks and eliminating others. To show the large quantities of these rocks throughout the Basin-and-Range province, for example, would serve no purpose in clarifying the structure, and in some places would actually confuse the structural relations.

"*Structure contours.*—In all areas for which sufficient data are available, structure of stratified rocks is indicated by structure contours. Several problems had to be solved to secure a fairly uniform representation. A 500-foot interval seemed best adapted to the scale of the map. In some large areas a smaller interval could be employed to advantage, with considerable gain in details of the structural features. However in other areas the smaller interval would cause crowding and loss of clarity. Use of different intervals would give misleading effects, since structural features would appear unduly accentuated in areas employing small intervals, in comparison with areas of much higher structural relief but represented by contours more widely spaced. No doubt some students with particular interest in Ohio or Michigan will regard as unnecessary the generalization or omission of some well established domes and basins, since in that region of gentle dips the density of contours might be increased two or three times without confusion. However, on a map of this scale we can not have everything. In the judgment of the committee it is more important to provide direct and accurate comparisons between central Montana and northern Illinois than to portray every local feature possible without regard to the unity of the map. Many of the definite small-scale structures not cared for by contours are indicated by conventional symbols. For example a number of monoclines in Oregon can be shown only by symbols, whereas the large monoclines in the Colorado Plateau and in southern Montana are

prominently displayed by contours. Numerous small isolated anticlines also are marked by symbols.

"Geologic horizons for the contours of course change from one part of the map to another, and each horizon has to be clearly indicated and delineated. Wherever there was a choice among two or more horizons, in general the highest one that would give good results over a wide area was chosen. This rule is important especially in districts that are known from drilling data to have two or more unconformable sets of structural features— the 'layer-cake' geology of Levorsen. On a map of larger scale it would be possible to show these superposed structural systems by using contours of different colors. The committee decided against such a scheme as too involved for the map in general, but made an exception for Florida because of current interest in oil possibilities there and because of the simple structural relations that are involved.

"For a few parts of the map exact data for structure contours are lacking, and yet there is adequate information for representing the general form of major structural features. In such areas distinctive broken lines are used instead of the continuous lines which imply accurate data. Some authors have used the term structural contours to indicate the qualitative character of lines employed in this way. However, this slight variation of the ordinary term is ambiguous, and the topographic term *form lines* is adopted for this map.

"*Other structure-symbols.*—Although symbols generally have adequate explanation in the legend of the map, one or two of them merit special comment. The great thrust faults require a distinctive symbol to identify them clearly, especially in belts that have also numerous fold axes, as in the Appalachians. The symbol designed by Ralph D. Reed, with black triangles pointing to the over-riding mass, was chosen as meeting the requirements most satisfactorily. The traditional symbol for the anticline—a plain line with outward-pointing arrows—was found unsuitable in belts of closely spaced folds, and the wide line tapering in the direction of plunge, which has been used effectively by Kayser, Albert Heim, and others, was adopted for strongly compressed anticlines. Users of the map should be warned that this symbol is not entirely pictorial; the widest lines denote the highest and steepest folds, not necessarily the broadest.

"Some representations of faults in the Basin-and-Range province, at the borders of ranges and plateaus, require a word of explanation, since they do not accord with symbols commonly used on geologic maps. Faults that lie at the base of high, straight scarps are shown in full line, even if the faults are completely buried in alluvium. An example is the Grand Wash fault in western Arizona.

"*Age-relationships.*—There may be some disappointment that the map does not indicate geologic dates of deformation, as some other tectonic maps attempt to do. The committee gave this matter careful study, and decided against any general age-classification of structural features, because of complexities and uncertainties in the dating of orogenic episodes. If these episodes were as distinct as some textbooks represent them, and if every major structural unit could be related on satisfactory evidence to one or another phase, there would be unquestioned value in showing age-relationships, and ways of doing it could be devised. Two or three familiar examples will illustrate difficulties that are involved. In the Appalachian belt, dates of major deformations range from late Ordovician to Permian. Effects of two or three widely spaced episodes are superposed in some parts of the belt, and it is not yet known whether certain large thrusts and folds should be referred to the earliest or to the latest episode. Although the late-Jurassic and Laramide orogenies of western United States have been represented as distinct, accumulating evidence indicates successive episodes at short intervals between Jurassic and

early Tertiary, with cumulative effects in the wide belt between the Pacific Coast and the eastern Rocky Mountain border. In Nevada the Basin-and-Range faults, with dates of movement extending from Cretaceous to late Tertiary, are superposed on complex effects of the earlier orogenies in their several phases. Any scheme of symbols or colors to represent this confused history would have doubtful value in itself, and would not only complicate the map as a whole but also obscure some of the more essential information.

"General dates of igneous intrusive bodies, which are related to orogenic deformation, have been indicated without loss of clarity in the map. The committee is aware that some uncertainties attach to these age-designations also, especially in some of the western states. These uncertainties would be enlarged and multiplied by attempts at still closer dating.

"*Submarine contours.*—With the aid of Paul A. Smith of the United States Coast and Geodetic Survey, and Francis P. Shepard of the University of Illinois, submarine contours have been added to outline the continental shelves and slopes. Although a large contour interval is used, these contours portray many of the large submarine valleys and other topographic features of the sea floor which may have tectonic significance.

"*Features of base map.*—The map has been printed on a 'skeletonized' base on which geographic features and names were reduced to a minimum in order to avoid obscuring tectonic details.

"The committee realizes that the statements printed on the map acknowledging source materials are inadequate. Information accumulated by hundreds of geologists in at least two generations is embodied in the map. It would be difficult to trace some of the material to original sources. Fortunately a number of structural syntheses were published shortly before our project was started and while it was in progress. The geologic map of the United States, geologic and structural maps covering a number of separate States, and structure maps of various types published by commercial and research gealogists provided grist for our mill. In general, only the sources actually consulted have been formally acknowledged, although many of the works most useful to us rest on broad foundations laid by the researches of numerous earlier workers.

"Abundant though the published material proved to be, the map could not have been constructed on that basis alone. A vast store of unpublished information was made available through the generosity of geologists and organizations. Federal and State surveys, commercial companies, geological societies, and many college departments, as well as a large number of individuals, contributed original material and helped in the essential task of sifting and refining the older data. Although our intention has been to give credit for all of this help, possibly part of the record has been lost or forgotten in the complex affairs of a large committee during nearly ten years. We shall be grateful to have any omissions from the published list called to our attention promptly.

"The tectonic map has required much time for development, and we hope it may prove to have some virtues analogous to those of the oak and other organisms that grow slowly. However the committee releases it with a humble realization that it has limitations and imperfections. No doubt it contains some mistakes; any product of multiple authorship and resting on diverse types of source material is especially liable to error, and the conditions of wartime have interfered with adequate checking in the critical stages of final preparation and correction of plates. Mere mechanical errors can of course be found and eliminated before another printing. It is even more important that the committee receive information on omitted and new tectonic material, as well as suggested changes in methods

of representation, which may be incorporated in an improved edition. No map represents more than a stage in progress. A possible future edition of this tectonic map should be more accurate and complete, and in every way more serviceable. The committee will prolong its existence with this possibility in view, and will welcome frank criticisms and constructive suggestions at any time. Communications may be addressed to the chairman."

BOOKS RECEIVED.

RALPH E. DIGMAN.

Ontario Department of Mines, Toronto, 1944.

Vol. L, Part IV. **Geology of the Bryce-Robillard Area.** W. W. Moorhouse. Pp. 50; Pls. 7; Figs. 8; Geologic Map in color, 25″ × 40″; scale, 1″ to ½ mi.

Vol. L, Part VI. **The Relations of the Sudbury Series to the Bruce Series in the Vicinity of Sudbury.** H. W. Fairbairn. Pp. 13; Figs. 2. **The Bruce Series in Falconbridge and Dryden Townships.** H. W. Fairbairn. Pp. 4; Fig. 1; Geologic Map in color, 25″ × 40″; scale, 1″ to 1000 feet. **Breccia at Sudbury.** H. W. Fairbairn and G. M. Robson. Pp. 15; Pl. 1; Figs. 5.

Vol. L, Part VIII. **Geology of Gauthier Township, East Kirkland Lake Area.** J. E. Thomson and A. T. Griffis. Pp. 29; Pls. 2; Figs. 6; Geologic Map in color, 25″ × 40″; scale, 1″ to 1000 feet.

Vol. LI, Part III. **Geology of the Fort Hope Area.** V. K. Prest. Pp. 28; Pls. 9; Figs. 2; Geologic Map in color, 25″ × 40″; scale, 1″ to 1 mile. **Geology of the Eastern Extension of the Fort Hope Area.** V. K. Prest. Pp. 9; Pls. 4; Fig. 1; Geologic Map in color, 25″ × 40″, scale, 1″ to 4 miles.

Vol. LI, Part IV. **Geology of the Grimsthorpe-Barrie Area.** V. B. Meen. Pp. 50; Pls. 13; Figs. 6; Geologic Map in color, 25″ × 40″; scale, 1″ to 1 mile. **Geology of Kaladar and Kennebec Townships.** W. D. Harding. Pp. 23; Pls. 9; Figs. 2.

Vol. LI, Part VII. **Geology of the Cunningham-Garnet Area.** V. B. Meen. Pp. 26; Pls. 8; Fig. 1; Geologic Map in color; 25″ × 40″, scale, 1″ to 1 mile.

Vol. LI, Part VIII. **Geology of the Rennie-Leeson Area.** E. L. Bruce. Pp. 26; Pls. 9; Figs. 6; Geologic Map in color, 25″ × 40″; scale, 1″ to ½ mile. **Geology and Mineralization in the Northern Part of Stover Township.** H. C. Horwood. Pp. 12; Figs. 3.

Vol. LII, Part II. **Mineral Occurrences in the Haliburton Area.** J. Satterly. Pp. 96; Pls. 17; Figs. 12; Geologic Map in color, 25″ × 40″; scale, 1″ to 2 miles.

Bull. 46. **Hydro-Electric Development for the Mining Industry of Northern Ontario.** D. P. Douglass. Pp. 30; Pls. 5; Figs. 11; Map of area, 37″ × 24″; scale, 1″ to 20 miles.

Preliminary Report on part of the Beatty-Munro Area, District of Cochrane. J. Satterly. Pp. 8; Fig. 1.

Department of Mines, Quebec.

Annotated List of Publications of the Department of Mines of the Province of Quebec, 1883–1944. Pp. 39. 1944.

The Mining Industry of the Province of Quebec in 1942. Pp. 119; Pls. 4. 1943.

Calumet Island Area, Pontiac County. F. F. OSBORNE. Pp. 30; Pls. 3; Figs. 2; Geologic Map, Calumet Mines, 30″ × 16″; scale, 1″ to 200 feet; Geologic Map in color, Calumet Islands Area, 20″ × 15″; scale, 1″ to ½ mile. 1944.

Buteux Area, Abitibi County and Abitibi Territory. B. C. FREEMAN. Pp. 17; Pls. 2; Fig. 1; Geological map in color, 16″ × 26″; scale, 1″ to 1 mile. 1943.

Sept-Iles Area, North Shore of St. Lawrence, Saguenay County. C. FAESSLER. Pp. 26; Pls. 4; Geologic Map in color, 36″ × 20″; scale, 1″ to 2 miles. 1942.

Preliminary Report on Wakeham Lake Area, Saguenay County. J. CLAVEAU. Pp. 12; Fig. 1. 1943.

List of Geological Maps. Pp. 4.

Department of Mines and Resources, Ottawa, 1944.

Report of the Department of Mines and Resources, 1943. Pp. 207.

Rare-Element Minerals in Pegmatites, Yellowknife-Beaulieu Area, Northwest territories. A. W. JOLLIFFE. Pp. 23; Figs. 7.

Bibliography of Seismology. E. A. HODGSON. Vol. XIII, No. 15, Publications of the Dominion Observatory. Pp. 14, Price, 25 cents.

Miocene Foraminifera from Sumatra and Java, Netherlands East Indies. Pp. 113; Pls. 15; Figs. 2. Vol. 39, No. 3, Quarterly of the Colorado School of Mines. Golden, 1944. Price, $2.00. *The July, 1944 issue of the Colorado School of Mines Quarterly includes two parts: "Miocene Foraminifera of Central Sumatra" and "Small Foraminifera from the Miocene of West Java." Descriptions and illustrations of 173 species are included in the first paper. Of these, 27 species are described as new. Under the second title 107 species are described and illustrated.*

The Stratigraphy of Some Lower Ordovician Formations of the Ozark Uplift. J. S. CULLISON. Pp. 112; Pls. 23. Vol. XV, No. 2, Missouri School of Mines and Metallurgy. Rolla, 1944. *An excellent discussion of the Lower Ordivician strata which outcrop around the Ozark Dome. Type areas have been carefully studied and the region between the type areas have been observed. Measured sections are included and lateral extent of key beds noted. Much of the fauna of the formations is described and some faunal zones are established.*

Report on an Investigation of Water Losses in Streams Flowing East out of the Black Hills, South Dakota. C. B. BROWN. Pp. 45. Special report no. 8, Soil Conservation Service, U. S. Dept. of Agriculture. Washington, 1944.

SOCIETY OF ECONOMIC GEOLOGISTS

NOTE: The Annual Meeting and scientific sessions described below have been cancelled in order to accord with the request of the Honorable James F. Byrnes, addressed to technical, professional, and commercial organizations. A local meeting to be announced later will be held primarily to transact annual business of the Council of the Society. Notice of this meeting will be sent to Councilors and to members within commuting distance of New York City and will be published in the pages of this journal. Because of the care that has been devoted to the preparation of the annual program, the program and abstracts are, nevertheless, published below and will be distributed to the membership.

JOINT MEETING SOCIETY OF ECONOMIC GEOLOGISTS AND AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS FEBRUARY 19–22, 1945.

HOTEL PENNSYLVANIA, NEW YORK CITY.

PROGRAM.

N. B.—For all technical sessions, the place of meeting will be posted at the Registration Desk of the Society of Economic Geologists.

Attention is directed to related papers offered under the auspices of the American Institute of Mining and Metallurgical Engineers but not under the joint auspices of the Society of Economic Geologists. Such papers are listed at the close of this program and if available are published herewith in abstract form by express permission of the Institute, because of their special interest to members of the Society of Economic Geologists.

MONDAY, FEBRUARY 19, 1945.

No technical sessions of the Society of Economic Geologists will be held on February 19.

All-Institute Luncheon: Address by President Edward C. Elliott, Purdue University, "Freedom and Frankenstein." Members of the Society are cordially invited to attend. Tickets must be purchased at the A.I.M.E. Registration Desk.

The technical meetings of the Institute on this day and the Annual Smoker will be held at the Hotel Pennsylvania. The Smoker is at 7:30 P.M. and members of the Society are invited by the Institute to attend; but reservations must be made in advance through the office of the Secretary, American Institute of Mining and Metallurgical Engineers, 29 West 39th St., New York 18, N. Y.

TUESDAY, FEBRUARY 20, 1945.

9:00–12:00 A.M.

Recent Advances in the Geology of Industrial Minerals.

Auspices of the Industrial Minerals Division and Mining Geology Committee, A.I.M.E., and of the Society of Economic Geologists.

Co-Chairmen: H. M. Bannerman and C. H. Behre, Jr.

Fluorspar deposits of Mexico.	W. G. Kane, Babylon, Long Island, N. Y.
Domestic fluorspar sources as related to new uses.	J. S. Williams, U. S. Geological Survey, Washington, D. C.
Effect of radiation on the elastic constants of quartz.	Clifford Frondel, Reeves Sound Laboratories, Brooklyn, N. Y.
An X-ray study of the tantalum mineral simpsonite.	Paul F. Kerr and Ralph J. Holmes, Dept. of Geology and Mineralogy, Columbia University, New York City.
Quartz crystal deposits of Espirito Santo and eastern Minas Geraes, Brazil.	Fred L. Knouse, Foreign Economic Administration, Washington, D. C.
Asbestos fibre exploration and production forecasts by core drilling, Jeffrey Mine, Asbestos, Quebec.	George K. Foster, Canadian Johns-Manville Co., Ltd., Asbestos, Quebec.

TUESDAY, FEBRUARY 20, 1945.

9:00–12:00 A.M.

Deviation and Surveying of Diamond Drill Holes.

Auspices of the Mining Methods and Mining Geology Committees, A.I.M.E., and of the Society of Economic Geologists.

Co-Chairmen: Hugh M. Roberts and T. B. Nolan.

Some problems involved in the interpretation of diamond drill hole sampling and surveying.	John J. Collins, U. S. Geological Survey, Spokane 8, Wash.
Some notes on the surveying and controlling of diamond drill holes.	A. B. Yates, International Nickel Company, Copper Cliff, Ontario.
Deviation of diamond drill holes in the Metaline district, Washington.	Edward Sampson and A. B. Griggs, U. S. Geological Survey, Metaline Falls, Wash.
Tracing the course of a flat-angle drill hole by electrical equipotential lines.	Hans T. F. Lundberg, Toronto, Canada.
The application of oil well surveying instruments and technical services in the mining industry.	G. L. Kothny, Sperry-Sun Well Surveying Co., Philadelphia, Pa.
Symposium on list of questions prepared and distributed in advance.	Discussion from the floor.

TUESDAY, FEBRUARY 20, 1945.

12:15–2:00 P.M.

Meeting of the Council, Society of Economic Geologists, Private Dining Room; President John M. Boutwell presiding. Tickets should be procured at the Society of Economic Geologists Registration Desk.

Mineralogical Society of America: Luncheon and Award of the Roebling Medal of the Mineralogical Society to Dean Edward H. Kraus of the University of Michigan; 12:15–2:00 P.M.; Private Dining Room, Hotel Pennsylvania.

Members and friends are cordially invited to attend. Reservations must be made in advance with the Secretary, Dr. C. S. Hurlbut, Jr., Department of Mineralogy, Harvard University, Cambridge 38, Mass. Tickets must be picked up by 10:00 A.M., Tuesday, February 20, at the Society of Economic Geologists Registration Desk.

TUESDAY, FEBRUARY 20, 1945.

2:00–5:00 P.M.

Eastern Deposits of Zinc Ores and Related Minerals.

Auspices Society of Economic Geologists and Mining Geology Committee, A.I.M.E. Co-Chairmen: G. F. Loughlin and George M. Fowler.

General stratigraphy of the east Tennessee zinc deposits.	C. R. L. Oder, American Zinc, Lead, and Smelting Co., Mascot, Tenn.
Structural and stratigraphic control of zinc deposits in east Tennessee.	Johnson Crawford, Universal Exploration Co., Jefferson City, Tenn.
Zinc deposits of the Copper Ridge, Straight Creek, and Powell River areas of east Tennessee.	D. F. Kent and John Rodgers, U. S. Geological Survey, Jefferson City, Tenn.
Structural control in the eastern belt of the Sweetwater barite district, east Tennessee.	J. C. Dunlap, U. S. Geological Survey, Greeneville, Tenn.
The geology and fluorspar resources of the Babb fault system, Crittenden and Livingston Counties, Ky.	G. C. Hardin, U. S. Geological Survey, Washington 25, D. C.
Structure of the zinc-lead deposits of northwestern Illinois.	H. B. Willman, Illinois State Geological Survey, Urbana, Ill.
The structural relations of the upper Mississippi Valley zinc-lead district.	A. V. Heyl, Jr. and A. F. Agnew, U. S. Geological Survey, Platteville, Wis.

TUESDAY, FEBRUARY 20, 1945.

2:00–5:00 P.M.

Diamond Drill Hole Sampling and Estimation of Ore Reserves.

Auspices Mining Methods and Mining Geology Committees, A.I.M.E., and Society of Economic Geologists.
Co-Chairmen: Ira B. Joralemon and A. B. Yates.

Diamond drilling in exploration and development.	Robert S. Moehlman, South American Development Co., New York 6, N. Y.
Diamond drill sludge sampling and appraisal of a weathered ilmenite ore body, Piney River, Virginia.	Donald M. Davidson, E. J. Longyear Co., Minneapolis, Minn.
Exploration of an asbestos deposit by diamond drilling.	George K. Foster, Canadian Johns-Manville, Co., Ltd., Asbestos, Quebec.
Diamond drill sampling and estimation of ore at Mascot, Tenn.	C. R. L. Oder and A. T. Allen, Jr., American Zinc, Lead, and Smelting Co., Mascot, Tenn.
Diamond drill sampling calculations: a comparison of methods.	C. W. Greenhalgh, Remington Arms Co., Bridgeport, Conn.
Symposium on list of questions prepared and distributed in advance.	Discussion from the floor.

TUESDAY, FEBRUARY 20, 1945.

4:30–6:00 P.M.

Meeting of the Council, Society of Economic Geologists, Private Room, Hotel Pennsylvania (see Society of Economic Geologists Registration Desk). President John M. Boutwell, presiding.

TUESDAY, FEBRUARY 20, 1945.

7:00 P.M.

Annual Dinner of the Society of Economic Geologists: Informal; for members of the Society and their guests (men only), Harvard Club, 27 West 44th Street, (two blocks east and eleven blocks north, or about 20 minutes' walk, from the Hotel Pennsylvania, North Entrance). Reservations should be made by February 15 through the Office of the Secretary of the Society, 411 Schermerhorn Hall, Columbia University, New York City, 27; tickets already reserved should be obtained from the Secretary or picked up at the Society of Economic Geologists Registration Desk not later than 12:30 noon, Tuesday, February 20. The dinner will be followed by a brief Annual Business Meeting and reports from the officers, President-Elect O. E. Meinzer presiding. Address by Retiring President John M. Boutwell: "Economic Geology." After the dinner a special Council Meeting may be called or such a meeting may be set for Wednesday or Thursday, February 21 or 22 if necessary.

WEDNESDAY, FEBRUARY 21, 1945.

9:00–12:00 A.M.

Recent Advances in Mining Geology and Related Fields.

Auspices Mining Geology Committee, A.I.M.E., and Society of Economic Geologists.

Co-Chairmen: D. H. McLaughlin and H. E. McKinstry.

Military geology.	W. H. Bradley, U. S. Geological Survey, Washington 25, D. C.
Titaniferous magnetite deposits of the Lake Sanford area, N. Y. (To be read by title.)	R. C. Stephenson, Box 980, Laramie, Wyoming.
Geologic interpretation of magnetic exploration on the Mesabi Range, Minnesota.	R. H. B. Jones, Oliver Iron Mining Co., Duluth, Minn.
Geology of the Cerro del Mercado, Mexico's iron mountain. (To be read by title.)	W. A. Conley, American Smelting and Refining Co., Mexico City, Mexico.
The antimony deposits of Mexico.	D. E. White, U. S. Geological Survey, Washington 25, D. C.
On the chromite deposits of Turkey. (To be read by title.)	Falih Ergunalp, Geological Survey of Turkey and Columbia University, New York City.
Stratigraphic and structural features, Lower Matanuska Valley coal field, Alaska.	Thomas G. Payne, U. S. Geological Survey, Washington 25, D. C.

Luminescent phenomena as aids in the localization of minerals in polished sections.	Herman Yagoda, Industrial Hygiene Research Laboratory, Bethesda, Md.
The occurrence of tungsten and vanadium in manganese oxide ores and minerals.	Michael Fleischer, S. K. Neuschel, and J. M. Axelrod, U. S. Geological Survey, Washington 25, D. C.
Orientation analysis of fine-grained clastic sediments.	E. C. Dapples and J. F. Rominger, Northwestern University, Evanston, Ill.
Graphs for obtaining true thickness of a vein or bed.	F. Stuart Miller, War Production Board, 1029 Tempo R, Washington, D. C.

WEDNESDAY, FEBRUARY 21, 1945.

12:15–2:00 P.M.

Luncheon Meeting, Committee on Mining Geology, A.I.M.E. This committee has cordially invited interested members of the Society of Economic Geologists to attend. Inquiry regarding luncheon tickets should be made at the Institute Registration Desk.

Luncheon Meeting, Division of Industrial Minerals, A.I.M.E. This Division cordially invites interested members of the Society of Economic Geologists to attend. Inquiry regarding tickets should be made at the Institute Registration Desk.

WEDNESDAY, FEBRUARY 21, 1945.

2:00–5:00 P.M.

Panel: Metals and Minerals in the Post-War Economy.

Auspices of the Mineral Economics, War Projects, and Mining Geology Committees, A.I.M.E.; of the Petroleum and Industrial Minerals Divisions, A.I.M.E.; and of the Society of Economic Geologists.

Co-Chairmen: C. K. Leith and Wilfred Sykes.

The speakers will deal in national terms with the following subjects:

Importance of the mineral industries in the post-war world.	H. DeWitt Smith, Newmont Mining Corporation, New York City.
Domestic mineral reserves and the future of American industries.	Elmer Pehrson, U. S. Bureau of Mines, Washington 25, D. C.
Foreign sources of American raw material.	Alan M. Bateman, Federal Economics Administration, Washington, D. C.
The future of the American petroleum industry.	Wallace E. Pratt, Standard Oil Co. of New Jersey, New York City.
International agreements on mineral access.	Herbert Feis, former advisor on international economic affairs, U. S. Department of State.

Discussion from the floor.

WEDNESDAY, FEBRUARY 21, 1945.

All-Institute Banquet: 7:00 P.M., Grand Ball Room, Hotel Pennsylvania. Open to members of the Institute if reservations have been duly made in advance through the Secretary, A.I.M.E., 29 West 39th St., New York 18, N. Y. Dinner dress ("black tie").

THURSDAY, FEBRUARY 22, 1945.

9:00–12:00 A.M.

Symposium on Ground-Water Recharge; Papers on Engineering Geology.

Auspices Society of Economic Geologists and the Mining Geology Committee, Industrial Minerals and Petroleum Divisions, A.I.M.E.

Co-Chairmen: W. S. Morris and W. J. Mead.

General principles of artificial ground-water recharge.	O. E. Meinzer, U. S. Geological Survey, Washington 25, D. C.
Artificial recharge of artesian limestone at Orlando, Fla.	A. G. Unklesbay and H. H. Cooper, Jr., U. S. Geological Survey, Tallahassee, Fla.
Artificial recharge of productive ground-water aquifers in New Jersey.	H. C. Barksdale and G. D. De Buchananne, U. S. Geological Survey, Trenton Trust Bldg., Trenton, N. J.
Artificial recharge of ground-water on Long Island, N. Y.	M. L. Brashears, Jr., U. S. Geological Survey, Post Office Bldg., Jamaica 3, N. Y.
Artificial recharge of glacial sand and gravel with cold, filtered river water at Louisville, Ky.	W. F. Guyton, U. S. Geological Survey, Federal Bldg., Louisville, Ky.
Work of the U. S. Geological Survey on ground-water supplies for war purposes in the United States.	Chas. L. McGuinness, U. S. Geological Survey, Washington 25, D. C.
Application of geology to engineering and ground water problems in Alberta.	J. A. Allan, Department of Geology, University of Alberta, Edmonton, Alberta.
Foundation exploration and geologic studies at Cherokee and Douglas dams, Tennessee.	R. A. Laurence (formerly of the Tennessee Valley Authority), U. S. Geological Survey, Washington 25, D. C.
A guide to geological investigations of dam and reservoir sites.	Edward B. Burwell, Jr., War Department Engineers, New War Department Bldg., Washington 25, D. C.

OTHER PAPERS OF AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

OF PROBABLE INTEREST TO MEMBERS OF THE SOCIETY OF ECONOMIC GEOLOGISTS

The place of meeting for these sessions will be posted at the Registration Desk of the Society of Economic Geologists.

MONDAY, FEBRUARY 19, 1945.

9:45–12:00 A.M.

Processing of Industrial Minerals.
Auspices Industrial Minerals Division.

Mining and milling of asbestos. (Color film.)	Courtesy Canadian Johns-Manville Co., H. K. Sherry, Johns-Manville Co.
Quartz crystals go to war. (Sound and color film.)	Courtesy Army Signal Corps, R. B. McCormick, War Production Board, Washington, D. C.
Production of pure crude phosphates by the Coleman process.	J. H. Coleman and H. S. Ten Eyck, Southern Phosphate Corpn., New York, N. Y.
Searles Lake as a major source of lithium.	W. A. Gale and L. A. Roe, American Potash and Chemical Company, Trona, Calif.

TUESDAY, FEBRUARY 20, 1945.

2:00–5:00 P.M.

Economics and Uses of Industrial Minerals.
Auspices Industrial Minerals Division.

Crucible grade graphite.	G. R. Gwinn, U. S. Bureau of Mines, Washington 25, D. C.
Postwar prospects for fluorspar.	W. H. Waggaman and O. C. Ralston, U. S. Bureau of Mines, Washington 25, D. C.
Lepidolite—its occurrences and uses.	John D. Clark, Foote Mineral Co., Philadelphia, Pa.
International trade in non-metallic minerals.	Oliver Bowles, U. S. Bureau of Mines, Washington 25, D. C.
Some properties of foundry sands.	Heinrich Ries, Cornell University, Ithaca, N. Y.
Glass sands and a glass industry in Puerto Rico.	J. Earl Frazier, 436 E. Dean St., Washington, Penna., and H. A. Meyerhoff, Smith College, Northampton, Mass.

THURSDAY, FEBRUARY 22, 1945.

9:00–12:00 A.M.

Miscellaneous Papers on Industrial Minerals.

Auspices Industrial Minerals Division.

Alabama flake graphite in World War II.	H. D. Pallister and R. W. Smith, U. S. Bureau of Mines, Box L, University, Ala.
Application of the ternary diagram to analysis and classification of bauxite reserves.	J. R. Thoenen, M. C. Malamphy, and G. K. Dale, U. S. Bureau of Mines, 603 Union Life Building, Little Rock, Ark.
Mineral raw materials used in dry colors for pigments.	E. R. Allen, Du Pont de Nemours Co., Newark, N. J.
Wear resistance tests on domestic materials for pebble mill linings.	Chas. E. Berry, Du Pont de Nemours Co., Wilmington, Del.
The phosphate rock deposits and industry of the western states.	Bertrand L. Johnson, U. S. Bureau of Mines, Washington 25, D. C.

ABSTRACTS

OF

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APPLICATION OF GEOLOGY TO ENGINEERING AND GROUND WATER PROBLEMS IN ALBERTA.

JOHN A. ALLAN.

The plains area of Alberta is underlain by Cretaceous and early Tertiary strata with older formations at or near the surface in the foothills belt east of the Rocky Mountains. The unconsolidated deposits are composed largely of a wide variety and an irregular distribution of glacial, alluvial and residual debris. The wide variation in the origin, composition and character of the partially indurated strata, and of the surface mantle present geological factors of importance in the construction of dams, reservoirs, tunnels, highways, airports and other foundations on which various structures are erected.

Geological principles are similar regardless of latitude or longitude, but there are certain geological problems that differ with latitude, climate and surface formation. Engineering problems related to permafrost, road "glaciers" and muskegs, peculiar to northerly climates, require geological investigations.

There are many districts in Alberta where there is an inadequate ground water supply, and other districts where the problem is even more acute. This condition is in part due to neglect of known geological factors, presence of soluble salts in or near water-bearing strata, and incorrect drilling practice. Glacial deposits, especially sand and gravel, yield a water supply adequate for local needs. There are numerous sandstone beds and lenses that are water-bearing, but these aquifers change laterally within short distances or are rich in bentonite. One artesian basin has been developed in southern Alberta from the middle Upper Cretaceous sandstones. A closer co-ordination of geological factors and drilling practice is recommended in order to assure an available ground water supply in Alberta.

ARTIFICIAL RECHARGE OF PRODUCTIVE GROUND-WATER AQUIFERS IN NEW JERSEY.[1]

HENRY C. BARKSDALE AND GEORGE D. DEBUCHANANNE.

Artificial recharge by water spreading is practiced in several places in New Jersey. Rates of recharge ranging from 4,000 to 90,000 gallons per acre per day have been measured at the Perth Amboy Water Works, where artificial recharge of the Old Bridge sand, of upper Cretaceous age, has been practiced for more than 30 years. At the Duhernal development, which also draws from the Old Bridge sand, more than four million gallons daily is now derived from artificial recharge. This rate will probably increase with further lowering of the water table near the lake. For many years the Princeton Water Company has pumped water from a stream for recharging the Stockton sandstone, of Triassic age. The City of East Orange spreads the water from several small streams over parts of the intake area of the Quaternary beds supplying its wells. The estimated total recharge is about a million gallons daily. Closely related to artificial recharge are those instances wherein well sites are chosen to take advantage of potential recharge from existing bodies of surface water. At the Borough of Manville no water spreading operations are conducted, but about 80 per cent of the water from its wells is derived by recharge from the Raritan River.

INTERNATIONAL TRADE IN NONMETALLIC MINERALS.

OLIVER BOWLES.

Although each nation, in the future as in the past, will doubtless consider its problems of world trade from the realistic viewpoint of its own primary interest, nevertheless the Atlantic Charter blazes a trail in the direction of a freer interchange of mineral products for the mutual benefit of all nations concerned. The nonmetallic minerals are extremely complex for they consist of many grades and qualities differing greatly in value and use. No nation can supply all its needs from its own resources even though a certain degree of self-sufficiency may be attained by discovery of new deposits, by improvements in recovery and treatment, by utilizing new types of raw materials such as the atmosphere and the ocean, and by employing substitutes. As international trade is vital to a world-wide economy each nation should inventory its shortages and its surpluses.

The three principal reasons for imports are (1) economic advantage, (2) industrial necessity, and (3) to furnish luxury items. The second is of greatest importance in the national economy. In 1939 United States imports of nonmetallic mineral products were valued at 84 million dollars, and exports 36 million, compared with a total domestic consumption of 837 million. The principal imports were gems and precious stones, industrial diamonds, asbestos and potash salts, and the chief exports were sulfur, potash salts and phosphate rock.

International trade of the future will never become fixed and stabilized. It will fluctuate in accordance with changing needs, new discoveries and new uses, but its trend will, we hope, be in the direction of mutual advantage to all nations on a peace-time basis.

MILITARY GEOLOGY.[2]

W. H. BRADLEY.

Military Geology is the application of geology to terrain intelligence. The value of geology to military intelligence is based on its power to predict and

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[2] Published with the permission of the Director, Geological Survey, U. S. Department of the Interior.

interpret the characteristics of terrain features in enemy-held or advanced territory. Geology is equally applicable to strategic intelligence, which is based on research performed in this country and to operational intelligence, which is prepared in the war theaters. Using geologic maps and reports prepared and published by foreign geological surveys, experienced geologists and soils scientists can predict and define such characteristics of enemy terrain as suitability for movement, concealment, and cover of troops and equipment; the presence of magnetite sand which interferes with the operation of mine detectors; the depth it will be necessary to dig or drill to obtain either additional supplies of water or, in wet country, supplies of water that need relatively little filtering; what kind of drilling or digging problems they are likely to meet. Geologists and soils scientists predict sources and suitability of construction and surfacing materials; indicate soils that can be mechanically stabilized and those that are micaceous and therefore elastic and difficult to stabilize. A knowledge of the geology and soils science permits advance selection of accessible and topographically suitable sites where the ground is workable and can be stabilized and drained or, where topographically suitable sites are rare, to flag such hazards as cavernous ground, drainage difficulties, absence of suitable aggregate or binder, and soils of low bearing strength.

ARTIFICIAL RECHARGE OF GROUND-WATER ON LONG ISLAND, NEW YORK.[1]

M. L. BRASHEARS, JR.

In 1933, the water table in a large area in western Long Island was below sea level and potability of ground water was threatened by inflow of sea water. To prevent further overdevelopment, the New York State Water Power and Control Commission has required that water pumped from new wells for cooling and similar purposes be returned to the ground. During the summer of 1944, over 200 recharge wells and several recharge pits were returning water at the combined rate of about 60,000,000 gallons a day. Also in operation were several large recharge pits which return storm sewer runoff in Nassau County. The water is returned to glacial beds from which most of it is pumped but in places it percolates into the underlying Cretaceous formations. Well drillers have developed recharge wells capable of returning as much as 1,000 gallons a minute, many of them having been in operation for over five years without failing. Recharge pits dug in coarse glacial gravels are capable of returning about 1,000,000 gallons a day per acre of exposed surface. The legal requirement that water pumped for cooling be returned to the aquifer has caused a gradual decrease in net withdrawal of ground water but has increased actual use. Hence a rise in water levels has occurred in the critically overdeveloped area. Water levels reached lowest stage at end of 1941 and have recovered slowly since then. However, water levels are still far below sea level in many places and sea water continues to move inland in areas of heavy pumping.

A GUIDE TO GEOLOGICAL INVESTIGATIONS OF DAM AND RESERVOIR SITES.

EDWARD B. BURWELL, JR.

The history of geological investigations for engineering construction is replete with failures to discover faulty sub-surface conditions in advance of construction. Generally, these failures may be attributed to inadequate investigation or to faulty interpretation of the results of investigation. Systematic study and development of sub-surface conditions, employing the most modern techniques and tools in the

[1] Published with the permission of the Director, Geological Survey, U. S. Department of the Interior.

hands of experienced investigators, are required to give assurance that the site conditions have been adequately determined, especially in the case of those structures that are to impound and control the flow of water.

This paper discusses the methods and techniques of foundation explorations, outlines the phases of investigation, and describes the procedures followed by the Corps of Engineers, U. S. Army, in developing the geologic conditions of dam and reservoir sites.

LEPIDOLITE—ITS OCCURRENCES AND USES.

JOHN D. CLARK.

Lepidolite, a lithium-alumina-fluo-silicate mica, ranging in composition from polylithionite to lithium bearing muscovite is being used to an ever increasing extent in the ceramic and allied industries. This increased use has been encouraged by the 4.2–4.5 per cent Li_2O content and less than 0.10 per cent Fe_2O_3 content of the Lepidolite deposits in the district of Karibib, South West Africa, which are described. Analyses are given along with description of use in glass, enamel and chemical industries.

PRODUCTION OF PURE AND CRUDE PHOSPHATES BY THE COLEMAN PROCESS.

J. H. COLEMAN AND H. S. TENEYCK.

The process described in the paper is one producing, by a wet method, both pure and crude 75 per cent H_3PO_4 or stronger if desired. As intermediate products: two solida, one containing 50 per cent to 60 per cent P_2O_5, may be shipped in bulk and converted into crude acid at the market. The other, containing 70 per cent P_2O_5, may be shipped in bulk and converted at the market into pure phosphates.

SOME PROBLEMS INVOLVED IN THE INTERPRETATION OF DIAMOND DRILL HOLE SAMPLING AND SURVEYING.[1]

JOHN J. COLLINS.

Some debatable problems in sampling core, sampling sludge, cominging core and sludge assays, and determining the deviation of drill holes should be discussed in expectation of evolving proper answers from combined experiences of many geologists and engineers.

Examination of pre-existing exposures frequently indicates relative coring characteristics of ore and waste, suggesting "up-grading" or "down-grading" of core assays in relation to sludge. A minimum acceptable core recovery should be established for ore estimations. Core should be preserved; bonus payments to drillers should improve recovery. Even with non-coring bits accurate logging of holes is possible by stratigraphs or electrical means. The gamma ray method works even through casing. Dip and strike in single holes can be determined by polar core orientation or electrical dipmeter.

Except for poor recovery, sludge theoretically constitutes a larger, more accurate sample in common core sizes than does core. Permissible limits of recovery for estimating ore in various types of deposits are unpublished. Vital in sludge recovery are water return and slime overflow from the sludge box.

Differences between four published methods of combing core and sludge assays indicate the need for much more data on these methods. A frequently fundamental difficulty is the inaccuracy of core or sludge sample or both.

Small diameter holes are now best surveyed by Carlson and Radiolite compasses; great improvements would result from adapting certain oil-well instruments, especially the multishot camera. The size obstacle is being overcome.

Seventy-five selected, annotated references are given.

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STRUCTURAL AND STRATIGRAPHIC CONTROL OF ZINC DEPOSITS IN EAST TENNESSEE.

JOHNSON CRAWFORD.

The East Tennessee zinc district is situated in the valley regions of the Appalachians. The outstanding structural features of the valley are folds and overthrust faults which have distributed the formations into a series of belts parallel with the long axis of the valley. The same formations, duplicated by thrust faulting, outcrop in each belt. All exposed formations are sedimentary, and most of the zinc occurrences are in the Knox dolomite or the Maynardville limestone. The ore mineral at Jefferson City is sphalerite—lead free, and no other sulphides except minor amounts of pyrite. At present, all producing mines are in the upper 800 to 1,100 feet of the Knox dolomite, and are situated in Knox and Jefferson Counties. Five mines and two mills are in operation. The 4,000-ton Mascot mill of the American Zinc Company is supplied by ore from the Mascot, Grasselli, Athletic and Jarnigan mines. The 900-ton mill of the Universal Exploration Company is supplied by ore from its Davis mine near Jefferson City. Sphalerite is the sole primary ore mineral, and average tenors of crude ore vary from 2.5 per cent Zn. to more than 5.00 per cent Zn.

The orebodies are of the replacement and breccia filling type and occur in disturbed breccia zones, which are approximately parallel to the bedding. In detail, however, this long axis may be inclined to the bedding strike. The principal structural features of the ore deposits are jointing, tear faulting, low angle thrust faulting, and bedding plane movement. Associated dolomitization is conspicuous. A major overthrust fault bounds the area in a semi-circle. Within this compressive area tear fault zones are the vital structural features controlling the ore.

ORIENTATION ANALYSIS OF FINE-GRAINED CLASTIC SEDIMENTS.

E. C. DAPPLES AND J. F. ROMINGER.

Using laboratory material, this investigation has been directed toward the extension of methods of orientation analysis to fine-grained clastic sediments to determine their last depositional environment and direction of movement of the depositing agent. Two measurements are made on the projections of grains exposed on the bedding plane: (1) azimuth of elongation, and (2) end position (defined as the position of the larger end of the grain with respect to the smaller end). Grain elongation is measured by constructing two parallel tangents to the grain projection and separated by a minimum distance. End position is determined by construction of the least projection rectangle (least projection tangents to the grain projection and the perpendicular pair of tangents). The end of the grain having the greater area may then be determined by visual inspection.

Following are the results of the experiments:

(1) For sand deposited by running water the grains are elongate parallel to the current direction with their larger end upstream.
(2) For sand deposited by wind action the grains are elongate both parallel to, and perpendicular to the current direction, and have their larger end upstream.
(3) Grains rolled down a slope equal to the angle of repose of dry sand show a random distribution of elongation azimuth.

Should work in the field bear out the laboratory findings, the projection method furnishes a means of determining depositional environments and a quantitative measure of current direction prevalent during the deposition. Such information should prove of importance in determining the sources of petroliferous sediments, in tracing stratigraphic horizons, and in the construction of paleogeographic maps.

DIAMOND DRILL SLUDGE SAMPLING AND APPRAISAL OF A WEATHERED ILMENITE ORE BODY, PINEY RIVER, VIRGINIA.

D. M. DAVIDSON.

During an appraisal by drill sampling of a weathered ilmenite deposit, probably an igneous dike, at Piney River, Virginia, it was found that core recovery was negligible in the soft clayey ore, but due to the imperviousness of the clay a full return of drill water was achieved under sufficient pressure and velocity to raise to surface the heaviest mineral, ilmenite, thereby ensuring recovery of all the drill cuttings.

The hole was cased after each 5 foot run, and careful studies showed that while the average sample weight was slightly more than the calculated theoretical, this was due not to caving but to a constant small enlargement of hole during drilling.

Various checks, which included drilling duplicate holes and a comparison of drill hole results with the previous mine yield, proved beyond reasonable doubt that sludge sampling was a valid method for determining the value of the ore deposit.

STRUCTURAL CONTROL IN THE EASTERN BELT OF THE SWEETWATER BARITE DISTRICT, EAST TENNESSEE.[1]

JOHN C. DUNLAP.

This district, near the center of the Appalachian Valley and Ridge Province and forty miles southwest of Knoxville, consists of three parallel belts of Cambrian and Ordovician sediments separated by major thrust faults, with a barren belt between the eastern and the two western belts. Currently 3,400 tons of barite are produced monthly, all from residual deposits.

The deposits are restricted to the Beekmantown division of the Knox dolomite group, and occur principally in the limestone member of the lower Kingsport formation; but where structural conditions are favorable, deposits are also found in the Mascot dolomite and limestone above and in the Chepultepec dolomite below. The beds strike N. 50° E., and dip 10 to 20° southeast. Two types of minor structures, causing narrow fractured and brecciated zones, cut across the regional structure and are believed to control the mineralization. These are (1) "kinks" or sharp flexures caused by abrupt change in strike and (2) very gentle anticlines. The axes of the minor structures are inadequately known because of few outcrops, but probably strike about N. 70° W. with variations from N. 40° W. to due west.

Pyrite, fluorite, and barite, listed in order of deposition and increasing abundance, form banded veins in coarse breccia. Traces of sphalerite and galena are found in some of the deposits. Silicification, evidenced by the abnormally large amount of chert in the vicinity of the deposits, is a noteworthy feature.

The barite and associated minerals are believed to have originated from hydrothermal solutions rising through the fractured zones and spreading laterally along favorable beds.

THE OCCURRENCE OF TUNGSTEN AND VANADIUM IN MANGANESE OXIDE ORES AND MINERALS.[1]

MICHAEL FLEISCHER, S. K. NEUSCHEL AND J. M. AXELROD.

The occurrence of tungsten in manganese oxide ores was first noted by Penrose in 1890 and since has been discussed by several authors. Vanadium has been re-

[1] Published by permission of the Director, Geological Survey, U. S. Department of the Interior.

ported in four analyses of manganese oxides. New analyses in the Chemical Laboratory of the Federal Geological Survey have shown that these elements occur commonly in manganese oxide ores, especially in those from the southwestern United States. Over fifty new occurrences have been noted and many more will doubtless be found by systematic chemical testing.

In some deposits, the tungsten and vanadium content of the ore varies directly with the manganese content, indicating that the tungsten and vanadium are in the manganese oxide mineral. This is not true of a few deposits, including that at Golconda, Nevada. X-ray study and chemical analysis show that tungsten and vanadium occur most frequently in manganese oxides that contain barium. Over three-fourths of the tungsten-bearing samples studied are the barium manganate psilomelane. Over two-thirds of the vanadium-bearing samples studied are either psilomelane or hollandite.

No generalizations can yet be made as to the origin of the tungsten-bearing and vanadium-bearing manganese oxide ores. Many are of hydrothermal origin, but some appear to be secondary.

ASBESTOS FIBRE EXPLORATION AND PRODUCTION FORECASTS BY CORE DRILLING, JEFFREY MINE, ASBESTOS, QUE.

GEORGE K. FOSTER.

At the Jeffrey Mine of the Canadian Johns-Manville Company, Limited, 147,884 feet of core drilling has been done. This drilling may be sub-divided as follows:

From 1920 to 1930, 9,239 feet were drilled by Company-owned Calyx core drill cutting a 3½″ core. This type of drilling gave a satisfactory core but was discontinued due to slow penetration and high cost.

In 1923, 5,387 feet of diamond drilling was done by contractors with machines giving a 15/16″ core. Satisfactory logging was found difficult with this small core.

From 1928 to 1944, 37,804 feet of AX diamond drill holes were drilled by contract machines.

From September 1939 to December 13th 1944, 95,454 feet of AX diamond drill holes were drilled by Company-owned machines.

Coring bits used are oversize AX set with 222 bortz weighing approximately 22 carats. Principal features are a large water groove and shoulder, permitting quick clearance of sludge and fibre.

Cabins, tripods, corebox envelopes, etc. are metal to prevent wood getting into fibre.

Difficulties encountered are drilling overburden and caving of hole in broken or sheared ground.

Cores are logged by measuring and recording length and number of cross fibre veins 1/32 inch and over in width. From this information rock is classified as good, medium, or poor mill ore or as waste rock. This information is then projected on mine models. Production forecasts are then made up by correlating this classification with past production data and operating plans are made.

Details of drilling costs, diamond consumption, labor breakdown and bit footage are given in the report.

GLASS SAND AND A GLASS INDUSTRY IN PUERTO RICO.

J. EARL FRAZIER AND HOWARD A. MEYERHOFF

Superficial deposits of silica sand, characterized by a silicon dioxide content in excess of 99 per cent, occur in association with Miocene limestones in northern Puerto Rico. Haphazard distribution from Hatillo to Punta Cangrejos, a linear distance of 90 kilometers along or near the north coast, together with exceptional purity, suggests the possibility of precipitation from silica-bearing hydroxide solu-

tions, and the probability of concentration and washing on the sites of extinct artesian springs, which were situated above solution channels in subjacent limestone. The most extensive deposits are located in and immediately south of Lake Tortuguero, 35 kilometers west of San Juan.

Suitability of this sand for glass manufacture has been known for ten years, but prohibitive shipping costs have hindered export, while lack of capital has discouraged its use in a local plant designed to meet the heavy demand for glass containers. The isolation of Puerto Rico during the submarine campaign of 1942 prompted the local government to establish the Puerto Rico Development Corporation, and to give it funds for the founding of industries to make the Island more independent. Creation of the Puerto Rico Glass Corporation followed. In 1944 a plant with a production capacity of 400,000 gross of glass containers (20 ounce weight) was completed and will shortly employ 300 people for the extraction and treatment of local sand, limestone, feldspar, and barite; the handling of imported soda ash and feldspar; plant operation; packing and distribution of bottles, 80 per cent of which will be used by the 12 distillers and 31 blenders of Puerto Rican rum.

EFFECT OF RADIATION ON THE ELASTIC CONSTANTS OF QUARTZ.

CLIFFORD FRONDEL.

When quartz is exposed to a powerful beam of x-rays it fluoresces, becomes smoky black in color, and the elastic constants are altered. Other effective radiations include alpha, beta and gamma radiations from radioactive decay, cathode rays, and deuterons; neutrons and ultraviolet light are ineffective. The degree of response varies between specimens from different localities and sometimes in different parts of the same crystal. Natural smoky quartz is less affected than colorless quartz; rose quartz and tridymite are markedly responsive; amethyst is unaffected.

The change in elastic constants brought about by irradiation has important practical applications in the manufacture of quartz oscillator-plates. When an oscillator-plate is bathed in a broad beam of x-rays the frequency of oscillation decreases continuously, parallel to the change in color, until a saturation value is reached. This effect is now being utilized on a mass production scale to adjust oscillator-plates to a desired frequency. By oscillating the quartz plate during irradiation frequency adjustments of the highest precision can be attained. The fact that the frequency change is downward from the initial value is of special advantage in salvaging plates that are over the upper frequency tolerance.

The frequency change brought about by x-rays can be reversed and the oscillator-plate returned to its original frequency and color by baking over about 175° C. The rate of reversal increases with increasing temperature. Natural smoky quartz begins to decolorize at about 225° C. but the bleaching is not accompanied by any change in the elastic constants.

SEARLES LAKE AS A MAJOR SOURCE OF LITHIUM.

W. A. GALE AND L. A. ROE.

Searles Lake brine has long been known to contain small amounts of lithium in solution (about 0.015 per cent Li_2O), but it was not until 1938 that a very limited recovery, in the form of a new lithium compound (Li_2NaPO_4), was commenced at the Trona, California, plant of the American Potash & Chemical Corporation, as an incidental by-product of other operations. The natural brine (interstitial mother-liquor of the crystalline saline deposit) which is pumped to the Trona plant for the extraction of potash, borax, soda ash, sodium sulfate, bromine and other chemicals, carries with it approximately two tons of Li_2O values per day. Therefore, as a result of war-time needs for lithium, improved recovery

methods have been developed and placed in successful operation. The above mentioned lithium compound, formed as a solid phase during steam evaporation of the brine, is subsequently present as a highly dispersed suspension (turbidity) in certain liquors of the soda products recovery plant. This colloidal material is then concentrated by froth flotation in specially designed pneumatic-type cells, followed by settling, pressure filtration, washing and drying. The resulting "concentrate," containing 20–22 percent Li_2O, is fast becoming a serious competitor to all previously known commercial lithium ores.

DIAMOND-DRILL SAMPLING CALCULATIONS—A COMPARISON OF METHODS.

C. W. GREENHALGH.

The accuracy with which grade of a mineral deposit may be calculated, from diamond-drill assays, is dependent upon the reliability of the drilling and sampling program and determination of the correct relative importance to assign the core assay with respect to the sludge assay.

In the "volume" method of adjusting assays the importance assigned the core assay is the ratio of the volume of the core obtained to the volume of the hole drilled. Any sludge recovered, regardless of amount, is assumed representative of all cuttings made. In the "weight" method of adjusting assays the importance assigned the core assay is the ratio of the weight of the core recovered to the weight of core-plus-sludge recovered. The sludge sample is considered reliable only in proportion to the percentage recovered.

Core and sludge samples from AX and EX diamond drill holes taken from four manganese properties were adjusted by both the volume method and the weight method. Variations in adjusted assays were found (1) dependent upon core recovery, sludge recovery, and differences between core and sludge assays; and, (2) independent of grade of material drilled. The weight method gave emphasis to the core samples and the volume method gave emphasis to the sludge samples.

ARTIFICIAL RECHARGE OF GLACIAL SAND AND GRAVEL WITH COLD FILTERED RIVER WATER AT LOUISVILLE, KY.[1]

W. F. GUYTON.

Records obtained by the Geological Survey, United States Department of the Interior and the Geological Division, Kentucky Department of Mines and Minerals, indicate that industries at Louisville pumped about 62 million gallons a day of water from wells in 1943. This was over 20 million gallons a day more than the natural recharge to the glacial outwash sand and gravel from which the wells draw the water. The ground water is especially in demand because of its uniform low temperature throughout the year. In order to stop the resulting serious decline of water levels and decrease in yields of wells, the pumpage is now gradually being reduced. Also, the recharge has been increased about 2 million gallons a day by introducing water into the aquifer through wells.

During the spring of 1944 the Seagram and National distilleries helped solve a local shortage of ground water by recharging the underground reservoir with 1.7 million gallons a day of cold water from the municipal river-water supply. While this water was being added to the aquifer through several supply wells the plants were operated with additional city water, and the rest of the supply wells were kept idle. In this way, the large cone of depression in the water table that had been created by heavy pumping from the wells was practically filled with cold water from a combination of natural and artificial recharge. As a result, during the summer when the city water became too warm to be used in the plants, an in-

[1] Published with the permission of the Director, Geological Survey, U. S. Department of the Interior and the State Geologist of Kentucky.

creased and ample supply of cold water was available from the wells. It has been suggested that other industries at Louisville might adopt similar procedures for insuring adequate supplies of cold water during the summers.

CRUCIBLE GRADE GRAPHITE.

G. RICHARDS GWINN.

Graphite is a widely distributed mineral found in virtually every country of the world. Most occurrences, however, are of no economic importance because of poor quality, prohibitive mining and milling costs, inaccessibility, and poor location with reference to the industrial centers where graphite is used. The principal commercial deposits are found in Ceylon, Madagascar, Germany, U.S.S.R., the United States, Canada, Chosen (Korea), and Mexico. Included under Germany at present are the deposits in Czechoslovakia and Austria.

The type of graphite absolutely essential to domestic military or civilian industry is that required primarily in the crucible manufacturing industry. Although requirements are small the requisite qualities are exacting, and under current crucible manufacturing practices Madagascar and Ceylon material are specified almost entirely. Only a very small quantity of domestic graphite is suitable.

The evaluation of graphite for use in the manufacturing of crucibles is dependent on its carbon content, nature and size of flake or particle, toughness or breakdown, packed volume, burning rate, ash content, and production costs.

The excessive breakdown in mixing, lack of uniformity in carbon content, from shipment to shipment, and high production costs are perhaps the most serious defects of the domestic material. More uniform grading of the mined material and refinements in mixing technique to reduce the flake breakdown may affect an increase in the market for domestic flake in the crucible industry.

GEOLOGY AND FLUORSPAR RESOURCES OF THE BABB FAULT SYSTEM, CRITTENDEN AND LIVINGSTON COUNTIES, KENTUCKY.[1]

GEORGE C. HARDIN, JR.

The Babb fault system, in the central part of the Kentucky-Illinois fluorspar district, is a northeastward-trending complex of steeply dipping normal faults. This fault system is one of the most highly mineralized in the district, having yielded more than 150,000 tons of fluorspar.

The faults displace the relatively flat-lying limestones, sandstones, and shales of the Chester and Meramec groups of Mississippian age. Movement was principally vertical, and stratigraphic displacements range from a few feet to more than 700 feet. Detailed geologic mapping of the surface by the Federal Geological Survey combined with rather extensive underground exploration and diamond drilling both by private companies and by the Federal Bureau of Mines have demonstrated that the system includes 17 faults, 6 of which are known to contain fluorspar deposits of economic value.

The principal vein minerals are fluorite, calcite, and sphalerite, with minor quantities of galena, barite, smithsonite, and quartz. Fluorite and calcite were deposited throughout the period of mineralization, whereas the sulfides and barite were generally rather late.

Detailed surface and mine maps and a series of sections show the relationship of the ore to certain structural features and to the sedimentary rocks. There is evidence of some structural control of the veins, but in the Babb area, very wide veins are often composed principally of calcite and contain very little fluorspar.

[1] Published by permission of the Director of the Geological Survey, United States Department of the Interior.

THE STRUCTURAL RELATIONS OF THE UPPER MISSISSIPPI VALLEY ZINC–LEAD DISTRICT.[1]

ALLEN V. HEYL, JR. AND ALLEN F. AGNEW.

The district includes southwestern Wisconsin and adjacent parts of Illinois and Iowa.

The immediate rock succession is middle Ordovician limestones and dolomites, with subordinate shales.

The probable mineral paragenesis is quartz, dolomite, pyrite, sphalerite, galena, marcasite, barite, chalcopyrite, and calcite.

The district is on the southwest limb of the Wisconsin arch, which gives a general southwest dip to the rocks. Superimposed upon this regional structure are broad, gently dipping eastward-striking folds and northwestward-trending basins. The eastward-striking folds are thought to have been formed by north-directed forces as the northern limbs dip more steeply than the southern ones. Minor folds, with an amplitude of 20 to 70 feet, that are subsidiary to the broad eastward-striking folds, form prominent local structures.

At least two types of faulting are recognized, reverse faults and vertical tear faults. Nearly flat bedding plane faults in the basal incompetent Galena beds steepen upward in the competent beds to about 45°. They, in general, are confined to the limbs of the basins, and tend to swing around the basins to form arcs or ellipses. The tear faults strike northwest or north and cut the fold structures.

The zinc-lead ore bodies border the subsidiary eastward-striking folds and their localization is controlled by the reverse faults. The ore fills the faults and tends to spread in "flats" along the bedding planes in the footwall. Ore is also found along nearly vertical joints or minor reverse faults that parallel the axes of the northwestward-trending basins.

All structures are assigned either to a north-directed or southwest-directed forces or a combination of both. They form a pattern consistent throughout the district; this, plus their magnitude, excludes the older explanation of collapse. Minor thinning of the beds by solution and replacement occurs.

THE PHOSPHATE ROCK DEPOSITS AND INDUSTRY OF THE WESTERN STATES.

BERTRAND L. JOHNSON.

The once extensive phosphate-bearing Phosphoria formation was involved in a series of tectonic movements in late Cretaceous and early Tertiary times, during the development of the present Cordilleran province. These shattered its continuity and scattered the remnants over a presently visible area of about 100,000 square miles, extending from the Garnet Range in southwestern Montana to the Uinta Mountains in northern Utah, and from the Owl Creek Mountains in central Wyoming westward to the Blackfoot Mountains in southeastern Idaho.

The successive deformations, as they shifted areally, and as new factors entered, produced distinctive structural subprovinces. Under the influence of forces from the southwest and west, mobile areas between the great stable area of central United States and the Colorado Plateau buckled into great mountain arcs, partly encircling that plateau, stemming in the Colorado Rockies and terminating westwardly in the Uinta, Wind River, and Big Snowy Mountains, while between the last two arcs rose the nearly closed trapped arc of the Big Horn-Owl Creek-Shoshone Mountains. These ranges are mostly broad open folds with exposed pre-Cambrian cores. The western ends of the first three arcs formed westward pointing buttresses which later stopped the great overthrusts from the west. These bent into the reentrant between the Uinta and Wind River mountains and formed

[1] Published with the permission of the Director, U. S. Geological Survey.

the extensive Idaho-Wyoming phosphate region. In the north, in Montana, the structure of this overthrust belt was further complicated by east-west faulting and batholithic intrusions and only scattered blocks of folded and faulted Phosphoria remain.

GEOLOGIC INTERPRETATION OF MAGNETIC EXPLORATION ON THE MESABI RANGE, MINNESOTA.

R. H. B. JONES.

This paper reviews pertinent geology of the Biwabik iron formation, Mesabi range, Minnesota. This iron formation is divisible into four members. Each member is distinctive and in detail contains marker horizons which are recognizable throughout all phases of alteration from lean fresh rock to high grade iron ore.

Some beds have a larger magnetite content than others. Usually with ore development this magnetite content decreases as oxidation increases. Ore development includes both oxidation of iron minerals and silica removal by leaching and these distinct processes progress at variable rates for different locations and structures.

Magnetic intensities are dependent upon the magnetite content of the particular horizon of iron formations being considered. This in turn depends upon the subsequent degree of oxidation therein, upon the nature of the overlying and underlying horizons and on the extent of fracturing, folding or faulting.

The results of a number of magnetic surveys are described and the magnetic anomolies obtained are correlated with phases of ore development within the iron formation as determined by exploration.

ZINC DEPOSITS OF THE COPPER RIDGE, STRAIGHT CREEK, AND POWELL RIVER AREAS OF EAST TENNESSEE.[1]

DEANE F. KENT AND JOHN RODGERS.

The Copper Ridge, Straight Creek, and Powell River zinc areas lie roughly 15 miles south of the Virginia line in eastern Tennessee. In the Copper Ridge area, the easternmost of the three, the mineralization is mainly in the Ordovician Kingsport formation of the Knox group. The ore in this area consists of sphalerite and some pyrite, which replace and form breccia fillings in favorable beds along northwest tear faults, fractures and minor flexures which cross a monocline in the Knox dolomite. In the other two areas the ore is mainly sphalerite and galena, with heavy pyrite in places, and is found mainly on the Maynardville member of the Cambrian Nolichucky shale, though it does occur in the overlying Copper Ridge dolomite of the Knox group. The ore bodies in the Straight Creek area are along northwest tear faults en echelon, under a major overthrust. In places small ore bodies, much higher in grade than most of those in eastern Tennessee, that rake 30° or thereabouts have been formed along the intersections of faults and steeply dipping beds. The Powell River area, westernmost of the three, is on a broad northeast-trending anticline crossed by tear faults striking N65W to west, along which mineralization has been traced for several miles. In the Powell River area, as elsewhere, ore in the Copper Ridge dolomite is erratic and not promising. The New Prospect ore body, of partly oxidized sulfides, was found at the only place where the intersection of a tear fault and the Maynardville limestone is exposed. Prospecting along these faults for similar ore bodies in the Maynardville will require care, for known bodies are long and narrow, averaging 25 to 50 feet in width and 1,500 feet in length. Deposits in other parts of the Powell River anticline probably are at depths ranging from 600 to 1,000 feet.

[1] Presented by permission of the Director, the United States Geological Survey.

AN X-RAY STUDY OF THE TANTALUM MINERAL, SIMPSONITE.

PAUL F. KERR AND RALPH J. HOLMES.

The mineral simpsonite, an oxide of aluminum and tantalum or tantalate, from Tabba Tabba in Western Australia, was described and named by Bowley in 1939. Laue and Bragg x-ray data were furnished by Taylor at the same time. As originally identified the mineral was assigned a complex formula based upon the analysis of material now believed to be a mixture of microlite and simpsonite. Since the original description appeared occurrences of a tantalum aluminate have been found in two localities in Brazil along the boundary between the states of Paraiba and Rio Grande do Norte and at Bikita in Southern Rhodesia. X-ray diffraction studies have shown that the fundamental aluminum tantalate in each of the four localities mentioned yields the same Debye pattern. In addition Laue photographs have been obtained confirming the original x-ray data and computations of lattice constants have been made. One characteristic of simpsonite is the tendency to alteration to microlite. Crystals almost an inch across have been found but x-ray and optical examination indicate that the units usually consist of numerous small individuals. The Brazilian and African specimens are apparently more nearly pure simpsonite than the type material from Western Australia. The Australian and Brazilian occurrences are reported to be pegmatitic in nature. Simpsonite, because of its low columbium content, is a desirable economic tantalum mineral, but as yet production has been limited in amount. It is hoped that description of the material may lead to the recognition of other localities.

THE APPLICATION OF OIL WELL SURVEYING INSTRUMENTS AND TECHNICAL SERVICES IN THE MINING INDUSTRY.

G. L. KOTHNY.

This paper discusses some of the outstanding developments made in the use of well surveying instruments and the drilling techniques by the petroleum industry. It describes various types of instruments in use, their requirements and methods of operation, the benefits obtained from their use and how these instruments can be obtained. Instruments used by the mining industry are also briefly described and their performance compared. The adaption of the techniques used by the petroleum industry by the mining industry is advocated in view of the beneficial results to be obtained.

A simple method of determining the direction and the angle of the core samples taken off core trays is also briefly described.

FOUNDATION EXPLORATION AND GEOLOGIC STUDIES AT CHEROKEE AND DOUGLAS DAMS, TENNESSEE.

ROBERT A. LAURENCE.

Cherokee and Douglas Dams were built by the Tennessee Valley Authority, under a war emergency schedule permitting only twenty and thirteen months construction periods, respectively. Both rest on foundations consisting largely of calcareous rocks. Therefore, interpretation of geologic features as related to foundation conditions was of prime importance to the construction staff.

At both sites, foundation defects were directly controlled by minor features of stratigraphy and geologic structure. At Cherokee these were (1) a network of solution channels along joints in two limestone beds in a shale formation, especially at and near minor folds and cross-faults, (2) local deep weathering of calcareous shale beds, especially near the same minor structures, and (3) cavernous dolomite beds on a divide forming the reservoir rim.

Principal defects encountered at the Douglas site were (1) extensive solution openings under the river channel, especially along strike joints, (2) bedding-plane caves developed above thin cherty or shaly beds in the abutments, and (3) deep weathering in and near a deposit of volcanic ash and dolomite filling a pre-Chazyan sink hole.

Exploration, largely by diamond drills and large-diameter calyx drills, was carried on for six months before construction, as well as during much of the construction period, and invaluable geologic data were obtained from grout holes and daily observations in the excavated areas. Final limits of excavation, and methods and extent of foundation and rim treatment were adapted to the geological conditions to provide safe and water-tight structures.

TRACING THE COURSE OF A FLAT ANGLE DIAMOND DRILL HOLE BY ELECTRIC EQUIPOTENTIAL LINES.

HANS LUNDBERG.

The hole drilled at a flat angle, had wandered far off its intended course. Surveys using a small compass did not give a true picture on account of strong magnetic anomalies in the vicinity of the hole. An equipotential survey of the area revealed the course of the hole fairly definitely. Later drilling has amply demonstrated the accuracy of the electrical survey.

WORK OF THE U. S. GEOLOGICAL SURVEY ON GROUND-WATER SUPPLIES FOR WAR PURPOSES IN THE UNITED STATES.[1]

CHARLES L. MCGUINNESS.

Pumpage of ground water in the United States for public supply, industrial uses, and irrigation, which was already increasing rapidly, was greatly accelerated after the beginning of the war in Europe. Also, large ground-water supplies were developed for hundreds of military and naval establishments. The Geological Survey, working in cooperation with State, county, and municipal agencies, has assisted in the development of a large part of the new or increased supplies.

The technical staff of the Geological Survey engaged in ground-water investigations comprises about 100 geologists, engineers, and physicists. These specialists have made investigations for all kinds of war establishments in all parts of the country. Many investigations, such as that at Houston, Texas, are outgrowths of regular work started long before the war. Others are special studies requiring the work of several men for as much as a year. Most, however, are brief investigations resulting from urgent requests from another Government agency or industrial or municipal officials.

Examples of the more than 3,000 reports that have been prepared by the Geological Survey on ground water for war purposes in about 1,600 areas in the continental United States are those on a bomber plant in Michigan, a navy yard in Washington, a synthetic rubber plant in California, a refinery in Louisiana, a cantonment in Texas, an air field in New Mexico, an airplane factory in New York, a shipyard in Florida, a tire factory in Oklahoma, a relocation center in Utah, and an important public water supply in Tennessee.

GENERAL PRINCIPLES OF ARTIFICIAL GROUND-WATER RECHARGE.[1]

O. E. MEINZER.

The natural subterranean reservoirs formed by the porous and permeable rocks differ from surface reservoirs chiefly in that they have complex structure and

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great internal resistance to the flow of water. Their full utilization requires systematic development based on the geology and hydrology of the aquifer and the principles of hydraulics distinctive of ground water. Recharge may be greatly increased simply by pumping from wells and thus making storage capacity available. But the rate at which any group of wells can yield water perennially is limited by their ultimate cone of depression with maximum drawdown. Further utilization of the reservoir calls for new wells at adequate distances from the old wells or artificial recharge near them. In some places large supplies have been obtained by locating wells near a stream and developing a steep hydraulic gradient from the stream to the wells.

In an artesian aquifer geologic study with test drilling is needed to determine the actual intake area and its structural relations to the pumped wells, as a clay bed, fault, or other barrier may intervene between the assumed intake area and the wells. If the capacity of an artesian aquifer to carry water to the wells under maximum drawdown is less than the potential recharge in the intake area, further utilization can be accomplished only by recharge through wells penetrating the confining bed or by sinking production wells nearer the intake to steepen the hydraulic gradient.

Artificial recharge requires an effective process for getting the surface water into the saturated part of the aquifer—either by surface infiltration or through wells. The major requirement, in addition to a permeable terrane, is clean water that will not clog the intake or practicable means of periodically cleaning it. Various processes are now in use with constantly developing technique.

GRAPHS FOR OBTAINING TRUE THICKNESS OF A VEIN OR BED.

F. STUART MILLER.

This paper presents graphs from which can be read the correction factor that must be applied to the apparent thickness of a bed or vein, as measured along a drillhole or traverse, in order to obtain the true thickness.

DIAMOND DRILLING IN EXPLORATION AND DEVELOPMENT.

ROBERT S. MOEHLMAN.

The paper describes some of the limitations on the application of diamond drilling and some of the steps which should be followed in drilling programs to obtain reliable results.

Before embarking on a drilling program, all possible information should be obtained from geologic mapping of available exposures, supplemented by some trenching if necessary. If structural data are scanty, the first holes should be drilled to cut the mineralized structure a short distance from the known exposure.

Precautions necessary in taking core and sludge samples are described. To evaluate a sludge sample, the weight percentage of sludge recovered must be calculated. A series of charts are presented to facilitate this calculation.

Four methods of combining core and sludge assays are discussed. The preferred method is to combine core and sludge assays on basis of weights recovered, with a corrective factor introduced, as shown on charts, for sludge assays where recovery is in excess of 100 per cent.

In layered rocks of varying hardness, drill holes tend to deviate toward a perpendicular with the structure. Examples of such deviation at the Harvard Mine are shown. Dip of drill holes must be systematically measured where deviation is suspected.

After assay results from the drill holes have been combined and located in three dimensions, correlation of assay results for ore calculations must be based on structural data.

GENERAL STRATIGRAPHY OF THE EAST TENNESSEE ZINC DEPOSITS.

CHARLES R. L. ODER.

Zinc deposits occur in nearly every county in East Tennessee in Cambrian and Ordovician rocks.

Ore has been produced from the Shady, Rome, Maynardville, Copper Ridge, and Kingsport formations.

The Shady dolomite has yielded "carbonate" ore at Embreeville. It is composed of 1,000 feet of light gray, coarsely crystalline dolomite and dark gray, fine grained dolomite and limestone.

The Rome formation includes about 1,000 feet of variegated shales and red sandstones. Sphalerite sometimes occurs in thin calcareous zones in the upper shales.

The Maynardville limestone contains 60 to 250 feet of dark gray, fine grained limestone and dolomite some of which shows argillaceous laminae.

The Copper Ridge formation usually consists of 900 to 1,200 feet of dark sugary and light gray, fine grained, cherty dolomite with considerable limestone in the eastern areas.

Stratigraphic studies have proved valuable in the important Mascot-Jefferson City mining district. The following divisions of the Kingsport formation have been described, in descending order: (1) 101 to 135 feet of light and dark gray dolomite with a little limestone and numerous arenaceous and cherty horizons, (2) 44 to 50 feet of very light gray dolomite with concentric chert nodules, (3) 33 to 38 feet of light and dark gray dolomite and a little limestone, sometimes altered to crystalline dolomite, (4) 178 to 216 feet of brown limestone, frequently altered to crystalline dolomite, a moderate amount of light and dark gray dolomite, and numerous cherts.

Some crystalline dolomites in the Kingsport are believed to represent replacement of limestone.

DIAMOND DRILL SAMPLING AND ESTIMATION OF ORE AT MASCOT, TENNESSEE.

CHARLES R. L. ODER AND ARTHUR T. ALLEN, JR.

The American Zinc Company has used diamond drills in East Tennessee since 1912.

Most surface holes are vertical. They average 350 feet deep. Underground holes are vertical, horizontal and angled. They average about 100 feet deep.

The ore mineral, sphalerite, occurs in fractured and brecciated dolomite and limestone, some of which is cherty. Core recovery usually is 90 per cent or better.

Surface holes are completed with both EX and AX bits. Underground prospect holes are drilled with EX bits.

The entire core of individual samples is saved. No sludge is collected. No core is split. The average sample is 2 or 3 feet thick.

Estimations of ore reserves are based upon data from prospect holes and mine headings. The minimum commercial ore is the equivalent of a 10 foot thickness grading 2 per cent zinc. The polygonal area system is used for measuring ore.

Over 5,000 holes have been completed many of which were drilled with churn drills. The grade of ore mined is more similar to that indicated by churn than to that indicated by diamond drilling. It is desirable to mix the two types of drilling in new territory.

ALABAMA FLAKE GRAPHITE IN WORLD WAR II.

HUGH D. PALLISTER AND RICHARD W. SMITH.

The flake graphite deposits of Alabama apparently owe their origin to the recrystallization of carbonaceous sediments by the action of minute pegmatite intrusions in areas of structural deformation.

The Alabama flake graphite industry has flourished only in times of war when importations of foreign graphite for crucible use have been cut off. World War I was a boom period and in 1918 some 30 plants produced 7,795,475 pounds of flake graphite. The industry languished following the war and no graphite was produced from 1929 to 1939.

The U. S. Bureau of Mines began investigating the Alabama graphite deposits in 1940 and worked out modern recovery methods that were applied to satisfy the demands of World War II. A prospecting program disclosed reserves of over 25 million tons of graphitic schists. In 1942 the War Production Board authorized the enlargement of the one producing plant and the construction of two new plants. Production of flake graphite from these three plants in 1943 is estimated at 8,100,000 pounds. Resumption of imports from Madagascar late in 1943 shut down one of the new plants and curtailed production at the other.

Alabama flake graphite has not yet been able to compete with Madagascar graphite for use in the manufacture of any but small size graphite crucibles. The future of the industry must depend on meeting the higher carbon content demanded for other uses.

STRATIGRAPHIC AND STRUCTURAL FEATURES, LOWER MATANUSKA VALLEY COAL FIELD, ALASKA.[1]

THOMAS G. PAYNE.

High-volatile bituminous coal is produced from a Tertiary sequence, comprising channel and near-channel conglomerates and sandstones, flood-plain siltstones and silty claystones, stagnant-lake claystones, and swamp deposits of coal, bone, and coaly claystone. The sequence, about 6,000 feet thick, is subdivided into four parts, in ascending order: (1) 2,500 feet of alternating beds of sandstone, finer clastics, and some coal, mostly nonminable, (2) 600 feet of conglomerate, in two facies derived from different source areas, interbedded with arkosic sandstone, (3) 1,200 feet of coal measures, and (4) 1,700 feet of conglomerate and sandstone. These parts indicate alternating periods of weak and strong orogenic movements. Second-order sedimentary cycles in the coal measures began with dominance of river sedimentation forming sandstone, conglomeratic at the base, grading upward into finer clastics containing a few widely spaced coal beds; after this, quiescence in the source area led to long-sustained regional swamp and stagnant-lake conditions forming alternating beds of minable coal, bone, claystone, and intermediate types. Uplift brought a new cycle.

Stratigraphic intervals change in thickness laterally, as a result of differential compaction of sediments having marked lateral textural differences. Amount of compaction is evaluated to determine original sedimentational thickness used in correlation.

Mines are at both ends and along the north limb of a canoe-shaped syncline cut by two sets of transverse faults of horizontal displacement. An underthrust strike fault coincides with an area of tight subsidiary folding on part of the north limb.

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SOME PROPERTIES OF FOUNDRY SANDS.

HEINRICH RIES.

The production of moulding sands in the United States in 1943 amounted to about 9,000,000 tons, this increase being due to the great increase in the foundry industry occasioned by the war.

The value of sands for this purpose depends on the mineral composition and other properties of the sand such as grain size, shape of grain, bonding properties, permeability, etc. The importance of these properties is pointed out.

While many sands contain the requisite amounts of grain and clay bond—naturally bonded sands—much synthetic sand has been used in recent years. This is a mixture of silica sand and some type of clay and other bond, mixed in the proper proportions.

Standardized tests for determining the properties of sand mixtures are now widely used in many foundries.

DEVIATION OF DIAMOND DRILL HOLES IN THE METALINE DISTRICT, WASHINGTON.[1]

EDWARD SAMPSON AND ALLAN B. GRIGGS.

Surveying of many holes drilled by the U. S. Bureau of Mines in the Metaline District has shown surprising deviations. The holes start in the Ledbetter slate (Ordovician) and pass into the underlying gently dipping Metaline limestone (Cambrian) at varying depths, locally in excess of 1,000 feet. All holes start vertical but one had deflected as much as 35° at a depth of only 300 feet. In another case, a hole was found to be deflected 70° at a depth of 1,000 feet. These deviations were not recognized by the drillers by any action of the rods or machines.

Analysis of the survey data in the light of the observed geology indicates that the holes deviate most in the Ledbetter slate and scarcely at all in the Metaline limestone. The upper part of the "limestone" in most holes is a massive rock strongly altered by hydrothermal action and essentially homogeneous. The slate is only obscurely bedded but has a cleavage, varying from slight to strong, which is unrelated to bedding. Drill holes have deflected to become nearly perpendicular to the cleavage.

Several plans and cross-sections are submitted showing the behavior of various holes.

TITANIFEROUS MAGNETITE DEPOSITS OF THE LAKE SANFORD AREA, NEW YORK.

ROBERT C. STEPHENSON.

Large deposits of titaniferous magnetite occur associated with anorthosite and gabbro in the Lake Sanford area, Essex County, New York. The ore, gabbro, and anorthosite show consanguineous relations. Anorthosite grades through gabbroic anorthosite into gabbro but is locally intruded by gabbro. Structural and petrographic evidence suggests that gabbro was differentiated from anorthosite by filter pressing. Field and laboratory study of ore occurrences indicates that an ore residuum concentrated in the gabbro through magmatic segregation by normal crystallization and flowage. Ore occurs as bands which grade into gabbro and also as large masses which replace anorthosite. Ore in the gabbro is finer grained and richer in ilmenite than ore in anorthosite.

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APPLICATION OF THE TERNARY DIAGRAM TO ANALYSIS AND CLASSIFICATION OF BAUXITE RESERVES.

J. R. THOENEN, M. C. MALAMPHY AND GEORGE K. DALE.

Bauxite, an aggregate of aluminous minerals is difficult to identify without chemical analysis. In the accepted tri-acid method of analysis the alumina is determined by difference. Consequently, any errors in determining the minor constituents are reflected in the alumina determination.

Prewar grading of bauxite ores was based on specifications and therefore relative.

Calculation of reserves with weighted economic significance from drill hole records required quick and accurate analytical returns and a stabilized method of grading.

To satisfy these requirements a graphic chart following the ternary diagram was devised whereby chemical analysis can be checked instantly; the relation of analyses to mineral constituents shown at a glance and cumulative tonnages of various grades of ore presented for a specific orebody, related both to chemical analyses and mineral composition.

Specific examples are given for checking chemical analyses against mineral content. The manner of using the chart for depicting cumulative tonnages of ore in an orebody ranging from highest to lowest is also shown.

Presumably the same method of presentation can be applied to ores and orebodies other than bauxite.

ARTIFICIAL RECHARGE OF ARTESIAN LIMESTONE AT ORLANDO, FLORIDA.[1]

A. G. UNKLESBAY AND H. H. COOPER, JR.

The principal aquifer in the Orlando area consists of 900 feet or more of permeable artesian limestone of upper and middle Eocene age. As in most other parts of the Florida peninsula, this limestone is overlain by the Hawthorn formation of Miocene age which contains relatively impervious beds. The Hawthorn at Orlando is 45 to 100 feet thick and prevents or retards natural recharge to the limestone formations except where it is penetrated by what appear to be old sinkholes that are now filled with previous material.

Owing to the lack of adequate surface drainage, more than 175 wells have been drilled into the limestone in the Orlando area to drain streets, control lake levels, and dispose of sewage and other waste liquids. Generally the piezometric surface of the water in the principal aquifer is far enough below the land surface to allow drainage by gravity. As the limestones are cavernous, most of the wells have large capacities for draining water and seldom become clogged although a considerable amount of rubbish is carried into them.

The piezometric surface of the artesian water is conspicuously higher where drainage wells are concentrated, evidently because of recharge through the wells. However, the effect of the artificial recharge cannot be clearly differentiated from that of natural recharge. A deep-well current meter was used successfully to determine the horizons at which the polluted surface waters enters the limestone.

The investigation was made in cooperation with the Florida Geological Survey and the Corps of Engineers of the U. S. Army.

POSTWAR PROSPECTS FOR FLUORSPAR.

W. H. WAGGAMAN AND O. C. RALSTON.

There is ample evidence that the demand for fluorspar during the reconversion period will be greater than before the war.

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The curtailment of imports of fluorspar forced the United States to rely almost entirely on domestic deposits of this mineral, necessitating the expansion of existing mining facilities and an extensive exploratory program to develop new sources of supply.

Through the efforts of the Bureau of Mines and the Federal Geological Survey, the estimated domestic reserves of fluorspar have been increased six times over those of 1936. Technological research has resulted in improved methods of beneficiation, thus bringing low grade spars into the economic picture.

Although the present heavy demand for fluorspar is largely due to the enormous expansion of the steel and aluminum industries, new uses for hydrofluoric acid and its derivatives are advancing steadily and these promise to continue after peace is established. Among the relatively new fluorine products are refrigerants, aerosol insecticides, catalysts for organic synthesis and artificial cryolite. Numerous compounds of fluorine are now being manufactured on a commercial scale.

The possibilities of obtaining hydrofluoric acid and its salts as byproducts in the manufacture of phosphorus, phosphoric acid and superphosphate offer a promising field for research.

THE ANTIMONY DEPOSITS OF MEXICO.[1]

DONALD E. WHITE.

Most of the world's antimony deposits seem closely related to the circum-Pacific belts of Tertiary and Quaternary vulcanism and diastrophism. Nearly all of the Mexican production, which is about 20 per cent of the world total, is from a belt 1,400 miles long by 10 to 100 miles wide, in the pre-Tertiary rocks adjacent to the northeastern border and ends of Mexico's large area of Tertiary lavas. The antimony deposits are probably related to the Tertiary volcanic activity, though possibly less closely than most of the tin and quicksilver deposits.

The antimony deposits are largely in limestone, but some are in other types of rocks. The deposits in limestone are accompanied by silicification and locally by replacement by clay minerals; solution cavities are common. The original ore mineral was stibnite, that is generally oxidized; deposits in limestone commonly carry small amounts of mercury.

The dominant structural controls are faults, fractures, and anticlinal axes; chemical control may be important. In the three most productive districts, the ore is near contacts of limestone with overlying shale, adjacent to the feeding channels. In contrast, in most other districts in limestone, the shale is lacking. Six major districts are described; in one the ore is probably related genetically to the source of the associated quartz porphyry.

Mining has not gone below a depth of 600 feet, because of the relatively low value of the ore, and the horizontal control of the ore bodies by structure or lithology. The grade of the ore may also be related to the surface, but evidence is lacking. Wherever favorable structure exists, however, the deposits undoubtedly extend below the depths of present mining.

STRUCTURE OF THE ZINC–LEAD DEPOSITS OF NORTHWESTERN ILLINOIS.

H. B. WILLMAN.

The major zinc-lead deposits of northwestern Illinois are linear in outline, usually 100 to 200 feet wide and as much as 1 mile long, and have an orientation consistent with the regional joint system. The ore occurs principally along zigzag and inclined fractures "pitches," along bedding-planes "flats," in breccia

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zones, and disseminated. Solution of relatively soluble limestone strata underlying the Ordovician Galena dolomite appears adequate to account for the ore-bearing structures in the Graham-Ginte ore body, the only ore body now well exposed.

In the Graham-Ginte ore body the combined thickness of the "oilrock" and "glassrock" limestones, which underlie the Galena dolomite, varies as much as 20 feet. The thickness variations of the "oilrock" have been interpreted previously as sedimentary or resulting from structural incompetence, but the abrupt thinning of the limestone beds, the persistence of argillaceous and siliceous beds, the configuration of the insoluble material to joints, and the interpenetration of large blocks of "oilrock" and "glassrock," simulating stylolites, favor thinning by solution. The limestones underlying the "glassrock" is not exposed but it also may be thinned by solution.

The total vertical displacement of the beds is usually less than 10 feet and is not known to exceed 20 feet, which is no greater than the thinning resulting from solution.

Subsidence following solution explains the shallow structural trough in which the ore occurs, the fractures which converge upward above the trough, the bedding-plane openings, the brecciated "core-ground," and both the normal and reverse faults.

The local brecciation of the "pitch" and "flat" deposits before mineralization ended and the solution of limestone beds after mineralization suggests that solution, deformation, and mineralization were active contemporaneously.

LUMINESCENT PHENOMENA AS AIDES IN THE LOCALIZATION OF MINERALS IN POLISHED SECTIONS.

HERMAN YAGODA.

On exposure to ultraviolet light a considerable number of minerals become readily discernible as a result of fluorescence or phosphorescence. The resultant optical activity is usually associated with the presence of minor constituents. The fluorescent pattern can on occasion be utilized for the estimation of the trace element causing the activity, a notable example being the estimation of the molybdenum content of scheelites. An annular cold quartz ultraviolet illuminator is described which permits the microscopic examination of fluorescing minerals in polished sections. Photomicrographs up to 150 × magnification can be secured which are serviceable for aerometric analysis and for the study of mineral intergrowths.

The phosphorescence of minerals is best studied by direct contact printing avoiding the use of optical equipment. After irradiation the polished section is immediately placed on fast panchromatic film for about two minutes. On development a permanent record is secured showing the distribution of the phosphorescing constituents. This autoluminograph will often reveal constituents emitting radiations not visible to the eye but which activate the emulsion. By utilizing color sensitive film a true color replica is recorded of the evanescent phosphorescence. Such patterns have proven useful in the study of the Franklin, N. J. mineral deposits. The autoluminographs localize the willemite (green), clinohedrite (orange), and hardystonite (purple); the accompanying calcite, franklinite and zincite are non-luminescent and are depicted as voids in the autoluminographic pattern.

The thermoluminescence of hackmanite and certain varieties of fluorite can be recorded photographically by warming the thin section on a hot stage beneath the camera.

These luminescent properties are being employed in the study of the distribution of dust particles in lung tissue utilizing fluorescent hyalite opal and willemite as tracers for free and combined silica, respectively.

SCIENTIFIC NOTES AND NEWS

To Members and Associates of The American Association of Petroleum Geologists:

In compliance with the request of Hon. James F. Byrnes, the executive committee has cancelled the fourth war-time conference of the Association scheduled to be held at the Mayo Hotel, Tulsa, Oklahoma, March 20–22, 1945. In accordance with the constitution and by-laws of the Association, a corporation, the annual meetings of the business committee and of the Association will be held at the Mayo Hotel, Tulsa, Oklahoma, March 27, 1945. Only necessary Association business will be transacted.

Ira H. Cram,
Chairman of the Executive Committee

H. DeWitt Smith, who recently resigned as Executive Vice President of Metals Reserve Company, is in Peru for a brief trip.

Raymond Brooks, who has been in the employ of the Foreign Economic Administration, has returned from an assignment in Africa.

Alan M. Bateman has been appointed a delegate of the United States government to attend the International Conference for War and Peace in Mexico City.

Carlton D. Hulin is now in China for the Metals and Minerals Division of the Foreign Economic Administration.

Earl Irving is returning from field work in Central America for the F. E. A., and will be stationed with the Washington Staff of the Metals and Minerals Division.

D. H. McLaughlin has been made president of the Homestake Mining Company. He is also, and has been for some time, vice-president of Cerro de Pasco.

Graduate fellowships of the Mining Experiment Station are open for the academic year 1945–1946, at Missouri School of Mines and Metallurgy, Rolla, Missouri. Advanced academic work and research leading to Master's and Ph.D. degrees may be taken in Mining (including the Mining Geology and Petroleum options), Ceramics, Metallurgy or Geology. Applicants should address inquiries to Dean Curtis L. Wilson at the above mentioned school.

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